DO WE LIVE IN A MULTIVERSE?

ALL ABOUT SPACE

ISSUE 138
FEBRUARY 2023

WATER ON MARS

PLUS 24 INCREDIBLE DISCOVERIES ON THE RED PLANET

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ISSUE 139

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What would you say is the most amazing discovery on Mars? This issue, we recall 25 of the most incredible findings on – and around – the Red Planet. From water on its surface to the brand-new information relayed back from the rovers and spacecraft currently exploring there, did your favourite make our list?

Beyond the surface of its ruddy alien landscape, and beyond our Solar System, Milky Way Galaxy and universe in general, we look into if we could really be living in a multiverse – that's other universes that exist close to our own. We also give you a crash course in what might happen in these other universes... and whether another you could really exist somewhere out there.

If you're looking for something to do – aside from reading **All About Space**, of course – why not have a go at our space projects that you can try at home? Make your own telescope, build a Mission Control desk, launch a high-altitude balloon and so much more. We can't wait to see what you'll create, so be sure to share your creations with us via email, Twitter or Facebook. See you again at the end of February!

GEMMA LAVENDER
Content Director

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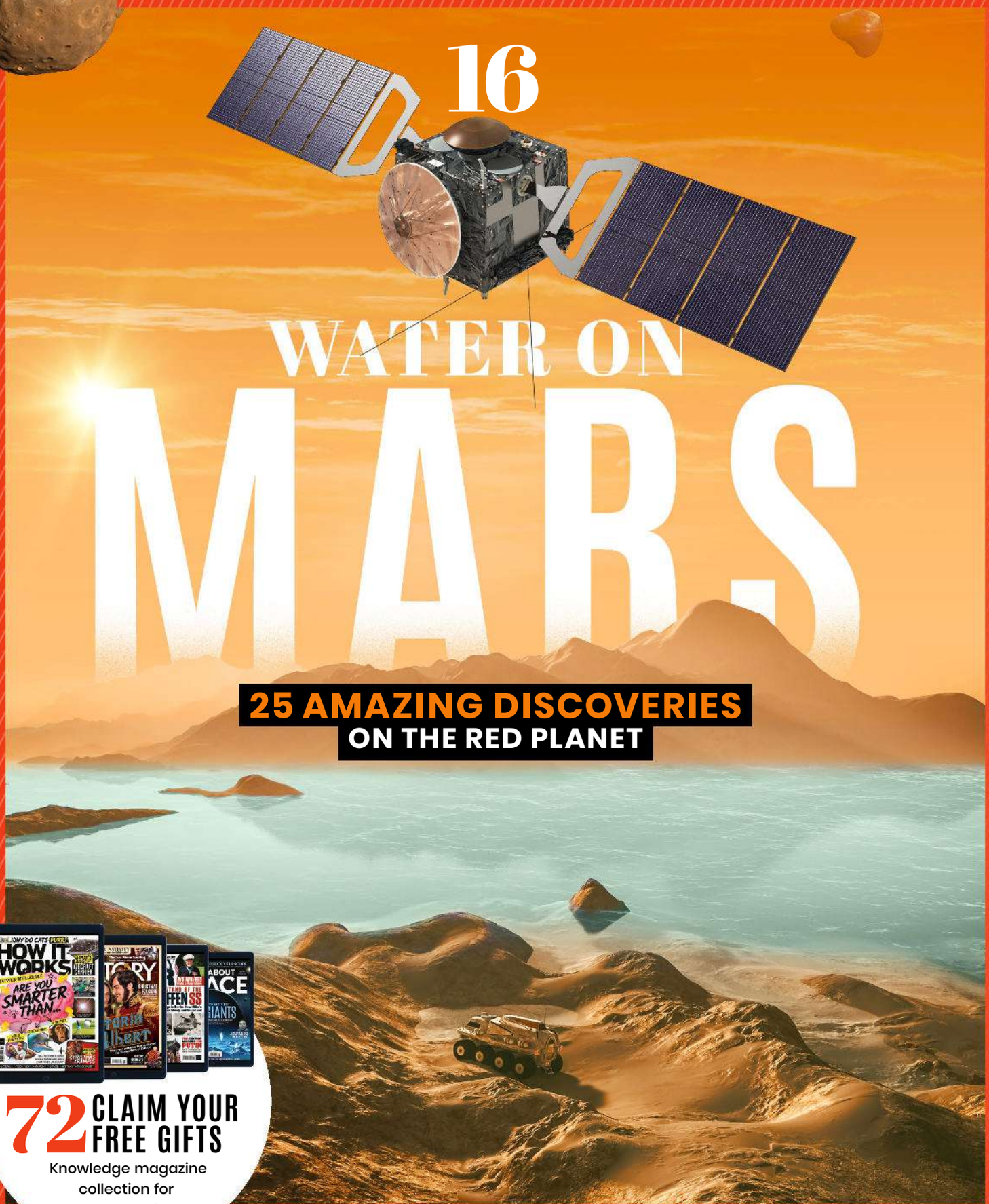

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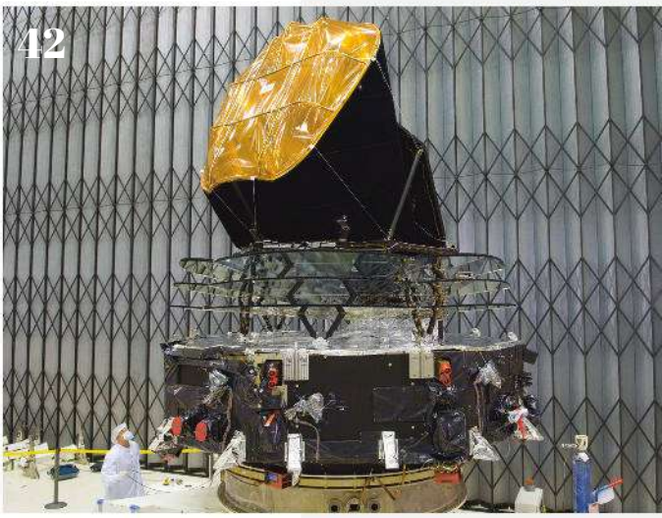

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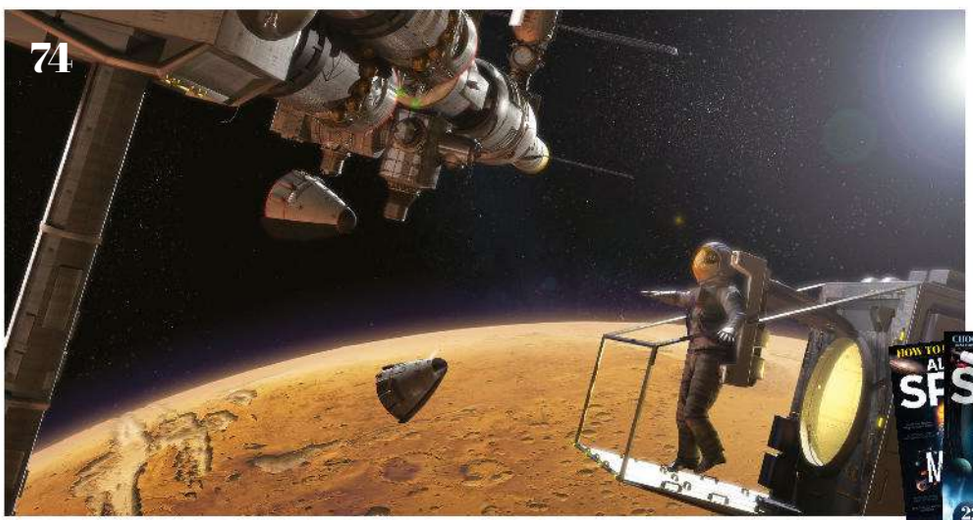

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22 November 2022

An Orion Nebula image tells a dramatic tale

A stunning new image of a stellar nursery tells a cosmic tale of death and rebirth. This photo of the Orion Nebula, the closest star-forming region to Earth, captures the transformation that occurs as massive stars die within the region, leaving the building blocks of the next generation of stellar objects. The image was created using data from NASA's retired Spitzer Space Telescope, the Wide-field Infrared Survey Explorer and the European Space Agency's retired Herschel Space Observatory.

Located in Orion, named after the Greek mythological hunter who was killed by the sting of a scorpion, the dust cloud has a creation story that's perhaps equally worthy of a place in mythology. Within the star-forming region, which is about 30 to 40 light years wide and located around 1,300 light years away, are two gigantic caverns carved out by giant stars, obscured by thick dust. As these massive stars blast out millions of times more radiation than the Sun, this radiation breaks apart dust grains, creating the giant voids that dominate the nebula. The remaining dust is whittled away by winds from the nebula's stars and by supernovae, tremendous cosmic explosions that occur when the massive stars die.

Threaded between the two gigantic hollows of the Orion Nebula are orange filaments that exemplify the tale of death and rebirth told by the image. Within these filaments is material from supernova blasts that could coalesce into the next generation of massive stars. Eventually, these newborn stars will begin ejecting tremendous amounts of radiation, blasting away the dust clouds that birthed them and reshaping the region again before they die in supernovae and once again enrich the region with heavy elements for the next stellar generation.

© ESA/NASA/JPL-Caltech

23 November 2022

Exposed heart of a galaxy

A new image shows the exposed heart of a distant galaxy in stunning detail, demonstrating the promise of a recent addition to the Very Large Telescope (VLT). It shows the galaxy NGC 1097, which is located 45 million light years from Earth in the constellation of Fornax. The image was taken by the Enhanced Resolution Imager and Spectrograph (ERIS), recently installed on the VLT, a telescope located at Cerro Paranal in northern Chile and operated by the European Southern Observatory (ESO).

Set to operate for at least ten years, ERIS will scan the universe in infrared, studying Solar System objects, exoplanets and even distant galaxies like NGC 1097. "We expect not only that ERIS will fulfil its main scientific objectives, but that due to its versatility it will also be used for a wide variety of other science cases, hopefully leading to new and unexpected results," Harald Kuntschner, an astronomer at ESO and project scientist for ERIS, said. The image of NGC 1097 was captured during ERIS' second batch of observations, occurring between August and November, and followed initial test observations obtained in February.

The ERIS image of NGC 1097 is dominated by the galaxy's dusty inner ring, which is dotted by bright spots that indicate the clusters of bright and hot newly formed stars found in stellar nurseries. Seen at the centre of the sparkling ring is the active heart of the galaxy, including a supermassive black hole that is consuming matter like gas and dust from its surroundings and blasting out bright bursts of radiation. The image demonstrates the incredible resolution of ERIS, since it represents an area of the sky no wider than 0.03 per cent of the full Moon.

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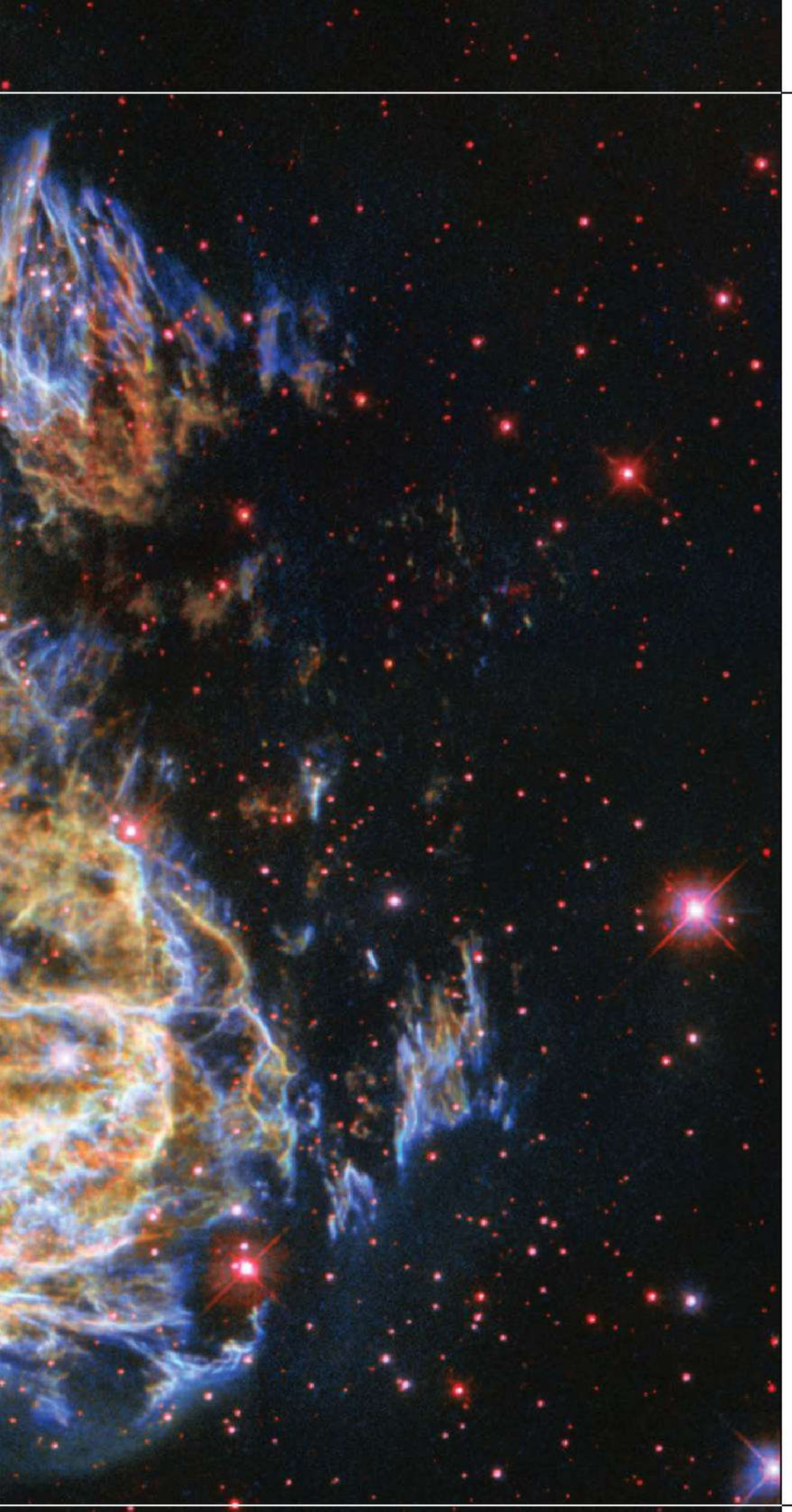

28 November 2022

Fireworks from a stellar death

The colourful, wispy remains of a star's violent death glow like fireworks in a spectacular image captured by NASA's venerable Hubble. Located in the Large Magellanic Cloud, a satellite galaxy of the Milky Way, the debris forms delicate sheets and intricate filaments of orange and blue. The stunning strands in the Hubble image are the remnants of a supernova, a powerful explosion triggered when a massive star reaches the end of its life. Called DEM L 19 or LMC N49, the stellar remains are located around 160,000 light years from Earth in the constellation of Dorado and represent the brightest supernova remnant within the Large Magellanic Cloud.

The light from this explosion would have washed over Earth thousands of years ago, and the sheets and fine ropes of material that the supernova left behind will eventually become the building blocks of the next generation of stars in the Large Magellanic Cloud. The 75-light-year-wide supernova debris cloud wasn't all the blast left behind, however. Scientists believe that this glowing cloud of material hides a rapidly spinning neutron star created when the core of the exploding massive star collapsed under the tremendous inward pressure of its own gravity.

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An illustration showing NASA's Cassini spacecraft flying through the plumes of Enceladus' south pole. A new orbiter could potentially seek life in the plumes without ever landing

Detecting life on Saturn's moon Enceladus would require 100 flybys through its geyser plumes

Reported by Sharmila Kuthunur

Detecting life on Enceladus could be achieved without even landing on the moon, but it wouldn't be easy. A team of researchers has found that it would require more than 100 flybys through a geyser plume from Enceladus with an orbiting spacecraft to capture signs of a cell – a crucial indicator to confirm the presence of life. This finding could help in designing future space missions to Saturn and Enceladus and to optimise scientific returns, especially if life isn't detected.

In 2015, NASA's Cassini flew through geysers spewing out of Enceladus' surface. Data from numerous flybys showed that the plume contained abundant dihydrogen (H_2), hinting at the presence of hydrothermal vents on the moon's seafloor, not unlike on Earth. The data also reflected generous amounts of carbon dioxide and methane (CH_4), both of which told us that methane-based life forms or methanogens could exist around hydrothermal vents on Enceladus.

Now, researchers have modelled the moon's hydrothermal vent environment to estimate the mass of such a methanogenic ecosystem to better understand how many cells could enter the plumes that eventually jet out of the moon's surface. "We were surprised to find that the hypothetical abundance of cells would only amount to the biomass of one single whale in Enceladus' global ocean," Antonin Affholder, a postdoctoral research associate at the University of Arizona, said.

By estimating cell densities, the team found that the moon's life-supporting region, or biosphere, around hydrothermal vents could be very small. Nevertheless, an adequate amount of cells and organic material from methanogens would enter the plume, increasing the chances that at least some of them would be captured by a visiting spacecraft. "Enceladus' biosphere may be very sparse," Affholder said. "And yet our models indicate that it would be productive enough to feed the plumes with just enough organic molecules or cells to be picked up by instruments."

If hydrothermal vents on Enceladus' seafloor harbour methanogens, these organisms would reside close to the vents like they do on Earth. Warm water released at such vents, mixed with cells of methanogens, rises until it reaches the moon's surface, where at least 100 plumes actively blast through cracks in the icy crust. Similar vents likely exist on Enceladus' seafloor. On Earth, environments surrounding hydrothermal vents support the creation and growth of yeti crabs, tube worms and a distinct species of shrimp with light-sensitive cells on its back. Given the uniqueness and diversity of deep-sea ecosystems around hydrothermal vents on Earth, similar vents on Enceladus are tantalising places to search for extraterrestrial life. Assuming that most of the methane comes from methanogens residing deep in the moon's ocean, researchers say that sampling a cell from an orbiting spacecraft is possible if a cell survives the journey to the surface.

Previous research indicated that 93 per cent of the plume material falls back onto the moon's surface, making sampling through flybys a time-sensitive challenge. Moreover, not every cell that enters plumes survives pressure changes as the plume travels upwards and out into space. Past experiments found that 94 per cent of the cells are destroyed due to depressurisation.

Perhaps a more worrying challenge would be the presence of non-living elements called organic abiotic amorphs. As the researchers outline in the new study, abiotic amorphs possess the same signatures as living cells, leading to a high risk of false positives. To overcome these challenges and maximise chances of sampling a real cell, Affholder's team found that at least 0.1 millilitres of a plume must be sampled, equivalent to 100 spacecraft flybys.

While 100 flybys sounds like a lot, the current plan for a NASA flagship mission, Enceladus Orbilander, shows that such an effort is within reach. Across a year and a half spent circling the moon, Orbilander might attain 1,000 flybys through the plumes. These samples would be crucial data points to hunt for the existence, or absence, of life on the moon. "The definitive evidence of living cells caught on an alien world may remain elusive for generations," Affholder said. "Until then, the fact that we can't rule out life's existence on Enceladus is probably the best we can do."

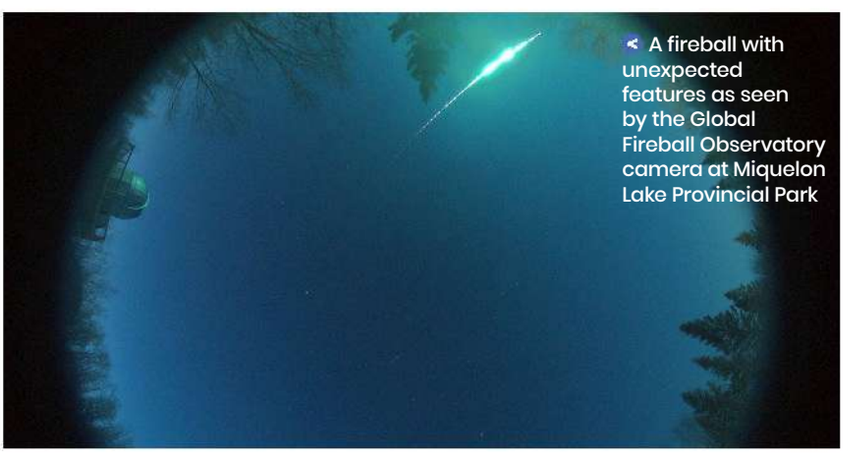
Fireball traced to a strange rocky meteoroid from the edge of the Solar System

Reported by Robert Lea

A rocky meteoroid that exploded over Canada last year was more extraordinary than it first seemed: it originated from the outer Solar System, where scientists thought only icy bodies exist. A cavalcade of astronomers caught images and videos of the meteoroid as it exploded over Alberta. By studying this data, researchers have determined that the meteoroid broke apart like a rocky object, surviving deeper into Earth's atmosphere than icy objects on similar trajectories. The analysis also suggested that the meteoroid came from the Oort Cloud, far beyond Pluto. Discovering a rocky body from this region could rewrite existing theories of how the Solar System formed. "This discovery supports an entirely different model of the formation of the Solar System, one which backs the idea that significant amounts of rocky material coexist with icy objects within the Oort Cloud," Denis Vida, a meteor physics specialist at Western University in Canada, said. "This result is not explained by the currently favoured Solar System formation models. It's a complete game changer."

Scientists have always believed that the Oort Cloud consists exclusively of icy objects. When passing stars displace these Oort Cloud objects, they head into the inner Solar System as comets. As they do, radiation from the Sun causes ice to change from solid to gas, blowing off material that forms the cometary tails of gas and dust that can stretch millions of miles. While astronomers haven't directly seen an object in the Oort Cloud, they have seen many cometary objects that started life in the region, and they've all been made of ice.

Rocky fireballs are fairly commonly observed, but all previous examples have originated from much closer to Earth, making this traveller, which has journeyed vast distances, completely unexpected. The University of Alberta caught the grapefruit-sized, two-kilogram rocky meteoroid using Global Fireball Observatory (GFO) cameras, developed in Australia. Western University researchers then calculated its orbit using Global Meteor Network tools. This revealed the meteoroid was travelling on an orbit usually occupied only by icy long-period comets from the Oort Cloud. "In 70 years of regular fireball observations, this is one of the most peculiar ever recorded," Hadrien Devillepoix, a planetary astronomer at Curtin University in Australia and principal investigator of GFO, said. "It validates the strategy of the GFO, established five years ago, which widened the 'fishing net' to 5 million square kilometres [1.9 million square miles] of skies and brought together scientific experts from around the globe," Devillepoix said. "It not only allows us to find and study precious meteorites, but is the only way to have a chance of catching these rarer events that are essential to understanding our Solar System."



A fireball with unexpected features as seen by the Global Fireball Observatory camera at Miquelon Lake Provincial Park

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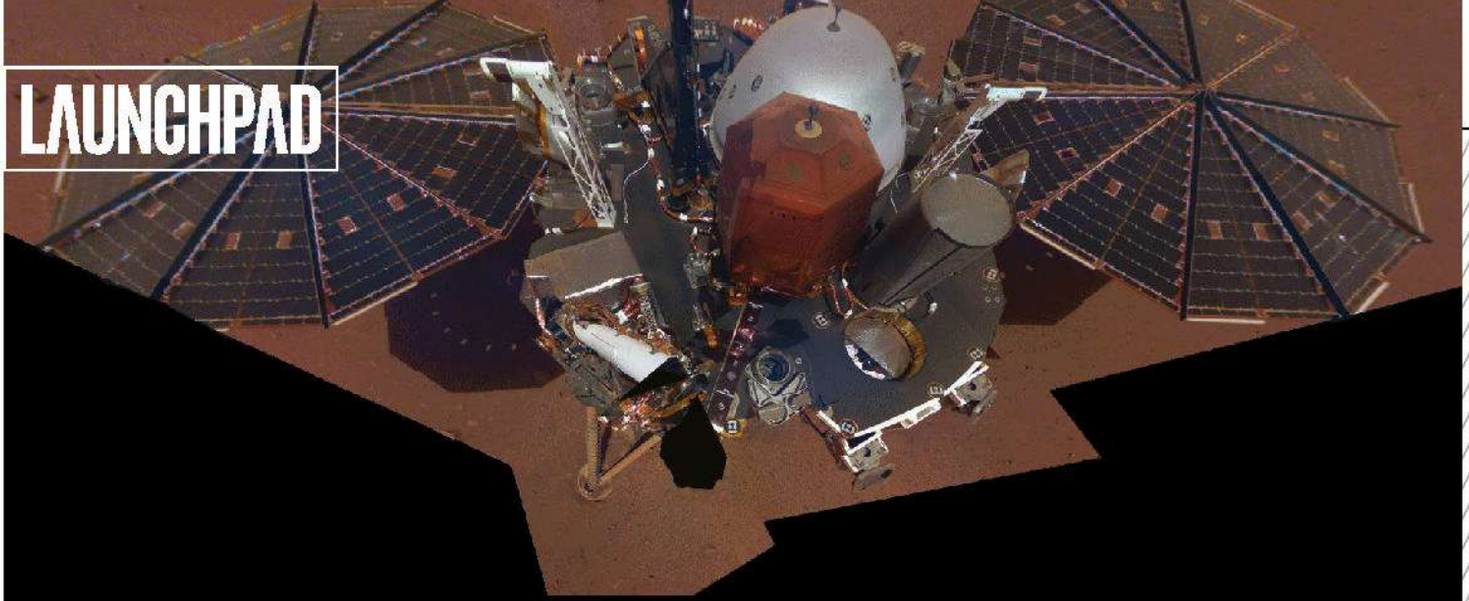


NASA's InSight lander recorded its biggest quake on Mars ever

A selfie taken by the InSight lander on Mars in early 2019

Reported by Andrew Jones

A marsquake detected by NASA's InSight lander in May last year was at least five times larger than the next-largest seismic event recorded on the planet. The quake occurred on 4 May and registered at a magnitude of 4.7. Another indication of the scale of the event is that InSight continued detecting waves from the record-breaking quake for around ten hours, while the after-effects of all previous marsquakes had subsided within an hour.

"The energy released by this single marsquake is equivalent to the cumulative energy from all other marsquakes we've seen so far," John Clinton, a seismologist at the Swiss Seismological Service at ETH Zürich, said. "Although the event was over 2,000 kilometres (1,200 miles) distant, the waves recorded at InSight were so large they almost saturated our seismometer."

The seismic event in May was also unusual because its epicentre wasn't near known nodes of activity. It also displayed characteristics of both types of marsquakes so far discerned: high-frequency waves with rapid but shorter vibrations and low-frequency waves with larger amplitude.

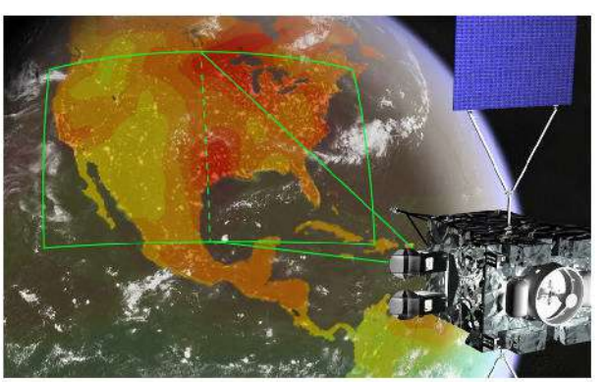
NASA has recently announced that InSight only has weeks left to live before its ceases functioning due to a buildup of dust on its energy-generating solar arrays. The lander has already successfully far outlived its primary mission lifetime of two Earth years.

NASA cancels climate change satellite to monitor greenhouse gases

Reported by Stefanie Waldek

NASA has cancelled the Geostationary Carbon Cycle Observatory (GeoCarb), a collaboration with the University of Oklahoma and Lockheed Martin that intended to put a greenhouse gas–monitoring satellite into geostationary orbit. GeoCarb would have measured levels of carbon dioxide, carbon monoxide and methane in the atmosphere about 4 million times per day. The mission was selected by NASA in 2016. "Decisions like this are difficult, but NASA is dedicated to making careful choices," said Thomas Zurbuchen, NASA's associate administrator for science. "We look forward to accomplishing our commitment to state-of-the-art climate observation in a more efficient and cost-effective way."

The decision to end GeoCarb was due to "technical concerns, cost performance and availability of new alternative data sources." The most recent anticipated cost of GeoCarb was $600 million (£494 million). As for those new data sources, they include the new Earth Surface Mineral Dust Source Investigation (EMIT) instrument that arrived at the International Space Station (ISS) in July, as well as the mission extension of the Orbiting Carbon Observatory-3 instrument that began work in 2019. NASA is also working on the Earth System Observatory, a series of Earth-focused satellites due to launch by 2030. These satellites will study aerosols, clouds, surface biology and geology and surface deformation and change, among other areas of research.



An artist's representation of GeoCarb studying carbon gases above Earth

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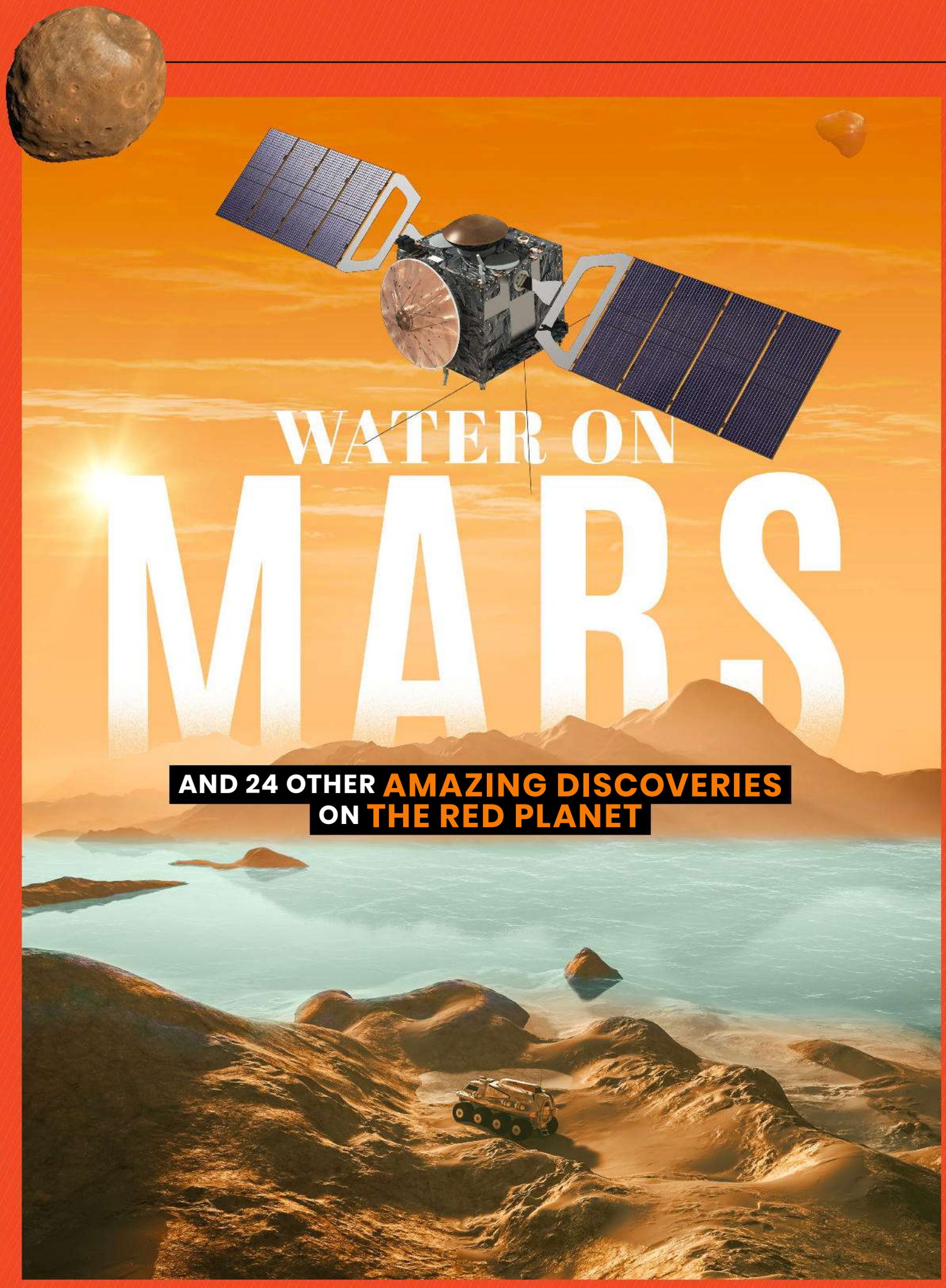


WATER ON MARS

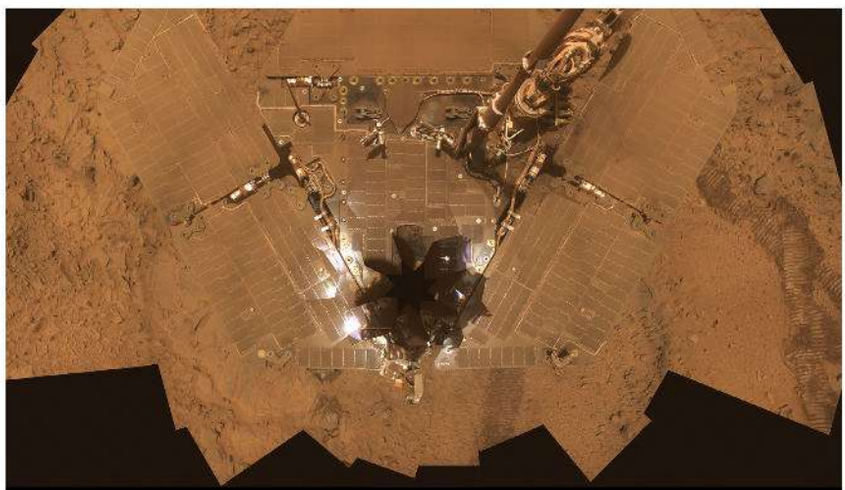
AND 24 OTHER AMAZING DISCOVERIES ON THE RED PLANET

1 MARS LOOKS LIKE A DEAD PLANET

Since the invention of the telescope in the 1600s, astronomers have been fascinated by the surface of Mars. It's too far away to resolve from Earth, and the atmospheres of both planets interfere with the passage of light, but they noticed dark and light patches that moved as the year passed, speculating that they might belong to clouds, seas and even forests. In the 19th century, Italian astronomer Giovanni Schiaparelli described a series of channels that he saw in the surface of the planet, imagining that there might be water on the surface, but a mistranslation of the Italian word 'canali' led American scientists, most notably Percival Lowell, to believe that the Red Planet was actually covered in canals, possibly built by intelligent life.

Hopes of an Earth-like planet were dashed when NASA's Mariner 4 captured the first ever close-up images of the surface during a flyby in 1965. The 22 stills showed craters, reminiscent of the scarred surface of the Moon, and revealed the planet to be a barren waste covered in red dust and rubble. Measurements detected no magnetic field, and barely any atmosphere. For years after, scientists thought Mars was a dead planet whose geological activity stopped billions of years ago. But subsequent missions revealed that there's much more to Mars than meets the eye.

Schiaparelli observed 'channels' on Mars



2 MARTIAN DUST IS MAGNETIC

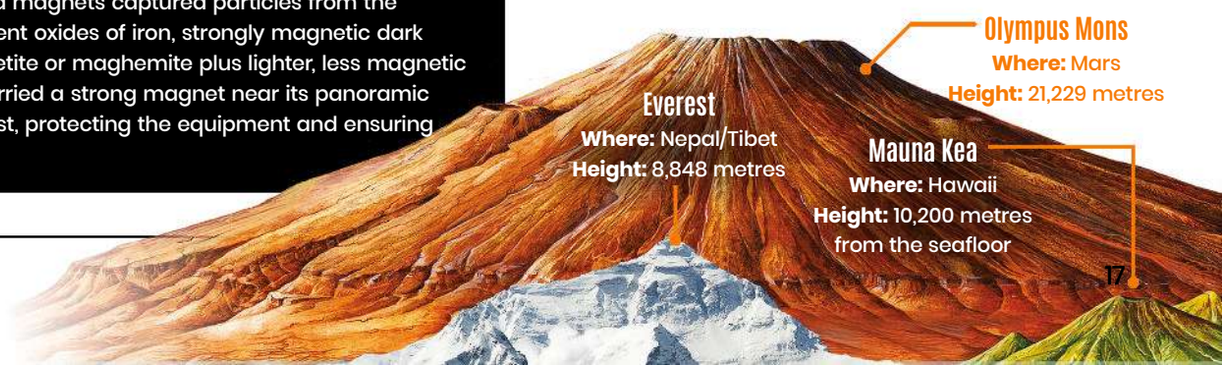
The Red Planet owes its distinctive colouration to iron, which was detected in high quantities in the soil by the Viking landers in 1976. Its surface is coated in a fine layer of dust, which after billions of years of winds and storms has been ground down to a consistency finer than talcum powder. The Imager for Mars Pathfinder (IMP), attached to the Carl Sagan Memorial Station, which landed in 1997, used the difference in atmospheric brightness throughout the day to measure the size of the airborne dust particles, revealing that they measure about three microns in diameter on average. In 2004, NASA's Spirit rover carried permanent magnets to the surface of the planet to probe the dust further, confirming that almost all of the dust on Mars is magnetic, whether in the air or on the ground. Two angled magnets captured particles from the atmosphere, revealing different oxides of iron, strongly magnetic dark material that is either magnetite or maghemite plus lighter, less magnetic haematite. The rover also carried a strong magnet near its panoramic camera that repelled the dust, protecting the equipment and ensuring the images remained clear.

3 IT'S HOME TO THE TALLEST MOUNTAIN IN THE SOLAR SYSTEM

The first orbiter to visit Mars was NASA's Mariner 9, tasked with mapping 70 per cent of the surface. When it arrived in 1971, the planet was engulfed in a dust storm that completely obscured the view of the ground below, and the orbiter had to wait for several months for the dust to settle. As the storm subsided, the highest points were revealed first, and four enormous volcanoes started to appear above the sinking clouds. They were large and domed in appearance, and the sides had gentle slopes reminiscent of shield volcanoes on Earth.

The tallest of the Martian shield volcanoes is Olympus Mons, measuring 624 kilometres (374 miles) across and extending nearly 26 kilometres (16 miles) above the ground. It easily dwarfs every other peak identified in the Solar System to date. For comparison, the tallest volcano on Earth, Mauna Kea in Hawaii, extends 10,200 metres (33,400 feet) above the floor of the Pacific Ocean.

© NASA; Getty; Webb

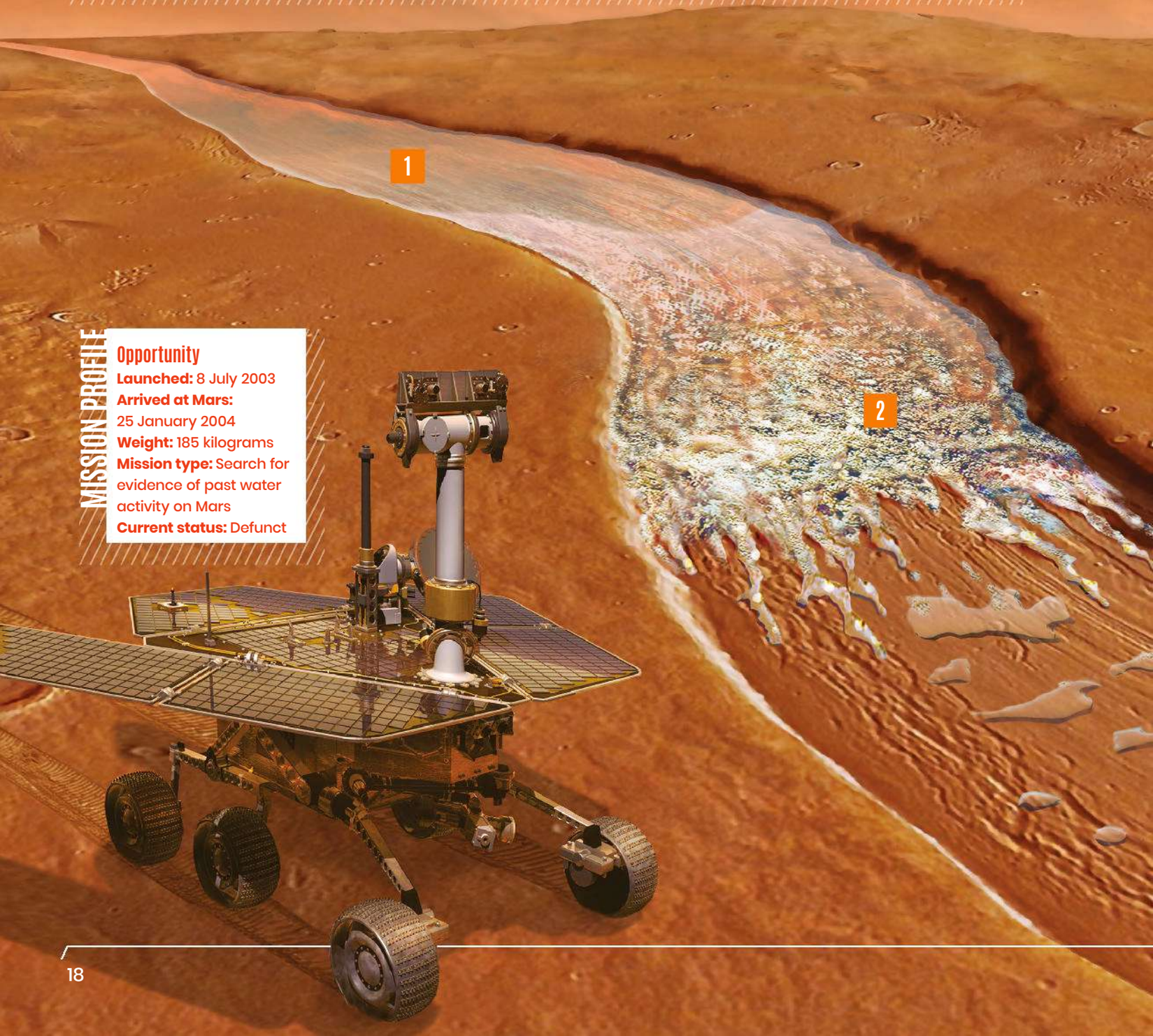


4 MARS USED TO HAVE LAKES AND STREAMS

Mars wasn't always as dusty and desolate as it is today. Maps made of the surface by Mariner 9, the Viking orbiters and the Mars Global Surveyor reveal networks of valleys across the southern hemisphere and show evidence of streams running down the sides of the mountains.

The most convincing evidence for liquid water on Mars has been provided by NASA rovers Spirit, Opportunity, Curiosity and Perseverance. Within just a few months of landing in Gale crater, Curiosity revealed an ancient streambed. On the ground are dunes made from sand and pebbles, too heavy to have been moved by the winds in the thin Martian atmosphere. The pebbles were smooth, like those you might find at the beach, and in the nearby rocks were veins of calcium sulphate, a mineral that would have been dissolved in the water that once flowed there. The rover also came across the site of an ancient lake containing clay minerals formed in neutral water and mudstone, made from particles laid down over time.

In 2014, Opportunity discovered another fresh water source on Mars, 8,000 kilometres (4,970 miles) away from the Curiosity site and positioned in rocks from the earliest point in Martian history, when the surface was likely more similar to Earth. The rocks in the area are smectite, a clay mineral formed in the presence of pH-neutral water.



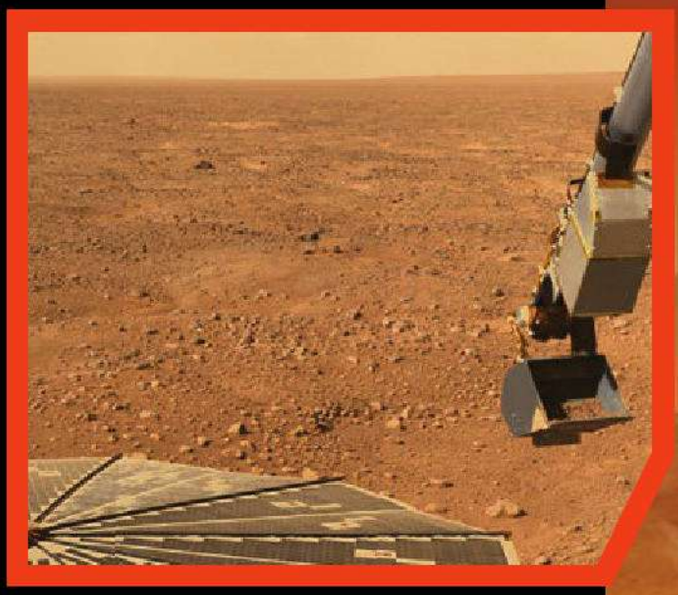
MISSION PROFILE

Opportunity
Launched: 8 July 2003
Arrived at Mars: 25 January 2004
Weight: 185 kilograms
Mission type: Search for evidence of past water activity on Mars
Current status: Defunct

5 IT WAS ONCE CAPABLE OF SUPPORTING LIFE

Following the repeated discovery of water on Mars, NASA switched its focus to searching for signs of life, and the Curiosity rover has been hunting since it landed in 2012. It has drilled into the sedimentary rocks in a location called Yellowknife Bay, revealing that the minerals beneath contain nitrogen, phosphorous, hydrogen, oxygen, carbon and sulphur – the building blocks of the biological molecules that make up all life on Earth. On our own planet, microorganisms known as lithoautotrophs can survive by using inorganic molecules to obtain their energy.

As the climate on Mars changed, the liquid water on the surface became trapped in the soil as permafrost, and today nothing can survive on the surface. The planet is bathed in radiation, battered by the solar wind and the atmosphere is painfully thin. However, on Earth bacteria can survive buried deep in Antarctic permafrost. Scientists are hopeful that if there was once life on Mars, traces will remain in the ice.



1 4 billion years ago

In the earliest history of Mars, the heavy bombardment was battering the inner planets of the Solar System, creating the craters now visible on Mars' southern hemisphere. The planet still had its atmosphere, and liquid water existed on the surface, possibly as a vast ocean that covered the northern hemisphere.

2 3.5 billion years ago

Mars underwent a catastrophic change, and within the space of a few hundred million years its core cooled, its magnetic field was lost and over 95 per cent of its atmosphere boiled away, preventing liquid water from existing on the surface. Over the next 3 billion years, volcanic activity periodically melted ice trapped beneath the surface, forming channels and gullies.

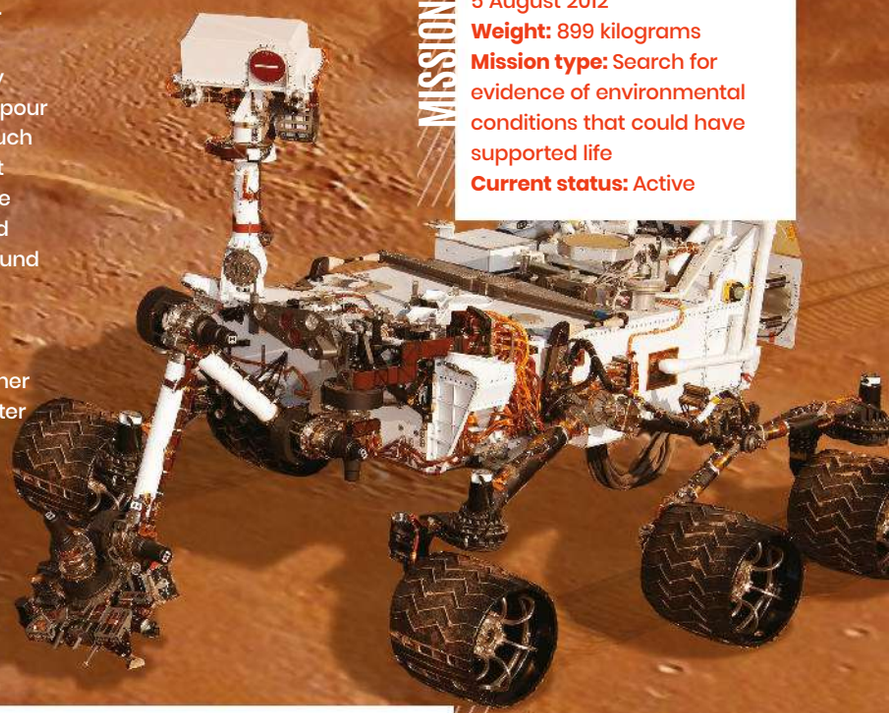
3 Present day

The atmosphere on Mars is thin, and the vapour pressure is low. Any water ice reaching the surface instantly sublimes into vapour and escapes. Much of the water that used to cover the planet is trapped beneath the ground as permafrost, and missions are ongoing to determine whether there's liquid water hidden below.

MISSION PROFILE

Curiosity

Launched: 26 November 2011
Arrived at Mars: 5 August 2012
Weight: 899 kilograms
Mission type: Search for evidence of environmental conditions that could have supported life
Current status: Active



MISSION PROFILE

Perseverance

Launched: 30 July 2020
Arrived at Mars: 18 February 2021
Weight: 1,025 kilograms
Main mission: Search for evidence of past water activity on Mars
Current status: Active

Spirit

Launched: 10 June 2003
Arrived at Mars: 25 January 2004
Weight: 185 kilograms
Main mission: Search for evidence of past water activity on Mars
Current status: Defunct

3

© NASA; Tobias Roetsch;

6 A DAY ON MARS IS 41 MINUTES LONGER THAN A DAY ON EARTH

Mars missions are planned and executed according to Mars time, where a day lasts for 24 hours and 37 minutes, compared to the 23 hours and 56 minutes of an Earth day. This number has been known since 1666, when Giovanni Cassini calculated the spin by watching surface features appear and disappear.

7 ITS GRAVITY IS ABOUT A THIRD OF EARTH'S

The orbital behaviour of satellites around Mars, both natural and artificial, have revealed that there is 62 per cent less gravity on Mars than there is on Earth. Mars is just half the size of Earth, and is only around 11 per cent of the mass, dramatically reducing its gravitational pull.

8 MARS ISN'T ROUND

NASA's Mars Global Surveyor spent three years creating a topographical map of the Martian surface. The northern hemisphere is low and flat, while the southern hemisphere is high, rugged and cratered, with a huge difference in elevation between the top and bottom of the planet.

9 A VAST CANYON OPENED UP AS THE CRUST STRETCHED

One of Mars' most striking features is Valles Marineris, named after the Mariner 9 orbiter that discovered it. The vast canyon stretches across the equator and is over 4,000 kilometres (2,485 miles) in length, seven kilometres (four miles) deep and is thought to have formed when the planet cracked as it cooled.

10 THE GROUND IS FILLED WITH WATER

One of the major questions surrounding Mars was what happened to its water. Today, it cannot exist as a liquid on the surface, and instantly sublimes into vapour before escaping the atmosphere into space. However, in the past the planet was covered with lakes, streams and possibly even oceans. Between 2001 and 2002, the Mars Odyssey Explorer looked for hydrogen beneath the surface of Mars, evidence that there might be trapped water. The map it returned revealed that beneath the dry carbon dioxide ice at the poles there is a huge quantity of water ice. The radar sounder onboard the European Space Agency's (ESA) Mars Express orbiter later revealed that there is enough potential water trapped under the Martian poles to cover the entire planet in an ocean 11 metres (36 feet) deep.

11 THE CORE MIGHT STILL BE MOLTEN

The lack of magnetic field around Mars indicates the core might have solidified, but the Mars Reconnaissance Orbiter revealed evidence of plate tectonics, with features some scientists say are reminiscent of the San Andreas fault in California, where two plates are moving horizontally past each other.

12 MARS HAS SEASONS

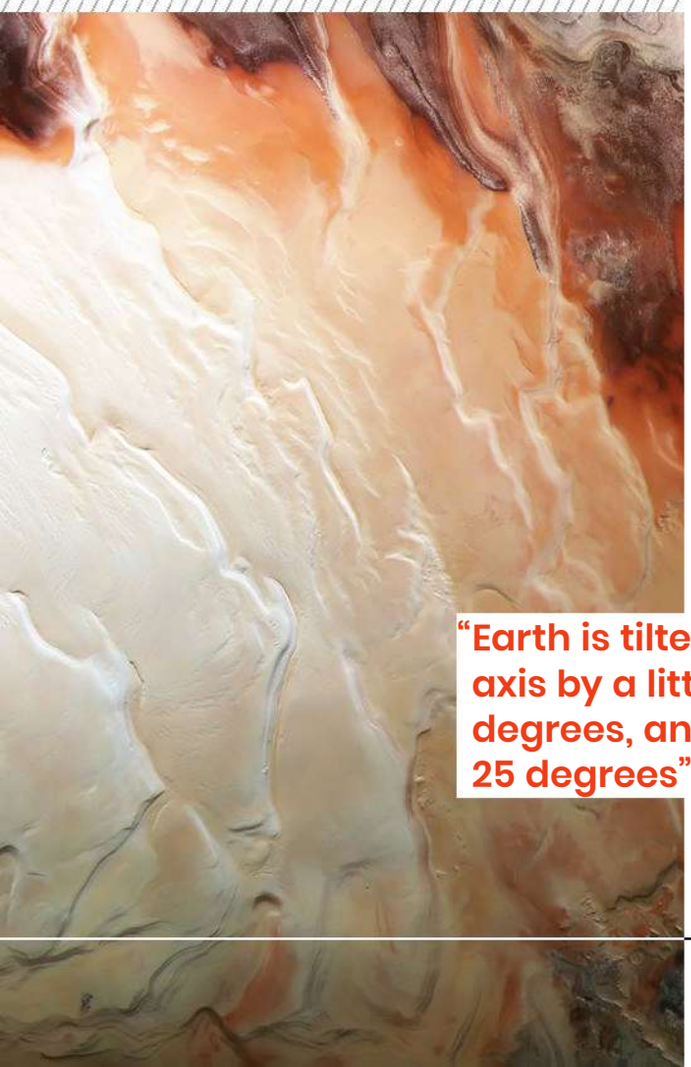
Seasons represent changes in day length and climate throughout the year, and are dependent upon a planet's distance to the Sun. If a planet is spinning straight up on its axis, the equator always gets the same amount of sunshine every day, but if the planet is tilted the daylight hours vary slightly throughout the year. Earth is tilted on its axis by a little over 23 degrees, and Mars by 25 degrees, and both experience seasonal variations.

Mars differs from Earth in that it has a more elliptical orbit, and at certain times of the year is much closer to the Sun. As a result, spring and summer are longer in the northern hemisphere than they are in the southern hemisphere, because when the north is tilted towards the Sun on the axis the entire planet is farther away in its orbit, and so travels slower.

While the northern hemisphere enjoys a long summer, the winters at the southern hemisphere are harsh, and for much of the time the south pole is in complete darkness. The temperature drops so low that carbon dioxide solidifies out of the air, forming a permanent cap of dry ice over the region. NASA's first landers to reach the surface of the Red Planet, Viking 1 and Viking 2, showed that atmospheric pressure drops by as much as 25 per cent as the gas freezes in the winter.

13 IT'S SHIFTED ON ITS AXIS

NASA's Mars Global Surveyor completed a full map of the surface in 2001, but something didn't quite match up. The positions of the shorelines where regions of water might have been weren't level. A team at the University of California, Berkeley showed that the shoreline movement might be down to the change in the spin axis of Mars. The spin axis of Mars is not fixed like Earth's, but has changed over its lifetime, and crust has moved relative to the axis over a distance of around 3,000 kilometres (1,864 miles) along the surface in the last 2 to 3 billion years. As planets spin, the motion causes them to bulge in the centre. The group calculated that deformation in the crust would have changed the water level to match the patterns seen in the shorelines.

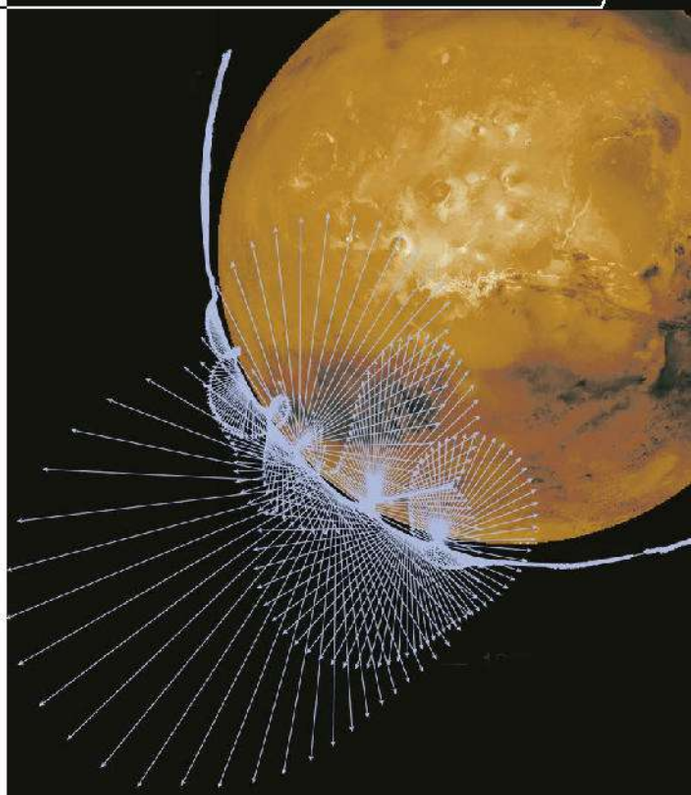


Tharsis Montes, a volcanic region of Mars with three huge volcanoes, sits on the crest of the planet's bulge

The direction and strength of the Martian magnetic field as it passes over the crust

At Mars' south pole, winter temperatures plummet as low as -153 degrees Celsius (-243 degrees Fahrenheit)

"Earth is tilted on its axis by a little over 23 degrees, and Mars by 25 degrees"



14 ITS MAGNETIC DYNAMO ISN'T WORKING

When Mariner 4 completed its flyby in 1965, it became apparent that something was wrong with Mars' magnetic field, and by 1989 a low-orbiting probe, Phobos 2, sent to Mars by the Soviet Union, had revealed that it's 3,000 times weaker than Earth's. Earth has a molten iron outer core that circulates inside the planet, powering an internal magnetic dynamo. It acts like a giant bar magnet, generating magnetic field lines that spring out from the poles and encircle Earth, deflecting solar wind and helping protect the atmosphere.

On Mars, these field lines are missing – rather than circling the planet, weak magnetic fields are fixed in specific locations, mainly in the southern hemisphere. Earth's magnetic field periodically changes direction, and its magnetic history is written into the rocks, with alternating bands of magnetic material deposited in opposite directions. NASA's Mars Global Surveyor found similar striped magnetic field lines in the ground of the southern highlands, indicating that at some point Mars had a functioning dynamo. These stripes are absent from the northern hemisphere, which formed much later in the history of the planet, suggesting the dynamo stopped functioning a few hundred million years after Mars formed.

© NASA; ESA; Getty;

15 MARS IS STILL LOSING ITS ATMOSPHERE

The atmospheric pressure on Mars ranges from around five to ten millibars, compared to 1,000 millibars here on Earth. The Red Planet is around 50 per cent smaller in diameter than Earth, and its lower gravity would have allowed the outer layers of the atmosphere to escape early in its life, particularly during energetic asteroid collisions. As the atmosphere started to thin, it would have provided less resistance to incoming asteroids, which would have resulted in even more collisions, beginning a vicious cycle of atmospheric loss. Without a functioning magnetic field, the Red Planet is also vulnerable to the effects of the solar wind.

The Mars Express orbiter carries an imager capable of detecting the effects of the solar wind. It showed that today, charged particles enter the Martian atmosphere, ionising the gases and allowing them to escape into space. NASA's Mars Atmosphere and Volatile Evolution (MAVEN) orbiter arrived on 21 September 2014, followed a few days later by India's Mars Orbiter Mission, or Mangalyaan. The two teams are collaborating to discover more about how Mars lost its protective sphere of gas.

MISSION PROFILE

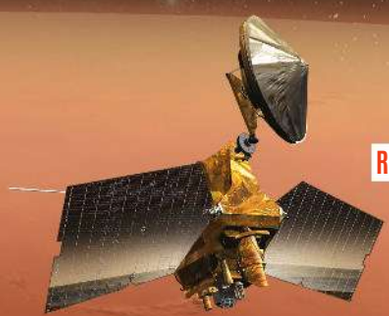
Mars Global Surveyor

Launched: 7 November 1996

Arrived at Mars: 11 September 1997

Mission goal: To characterise the surface features and geological processes on Mars

Current status: Contact ceased November 2006



MARS RECONNAISSANCE ORBITER

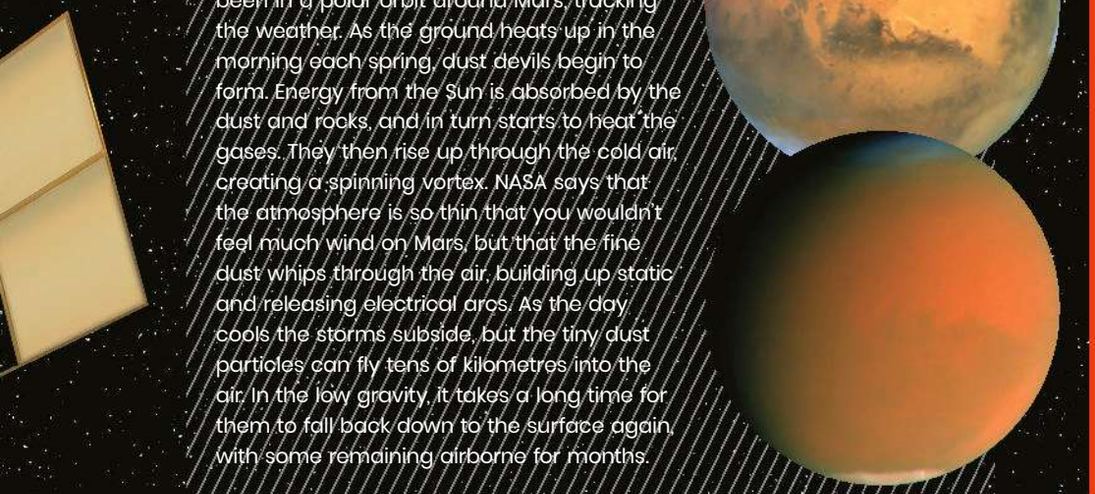
16 IT HAD A NEAR MISS WITH A COMET

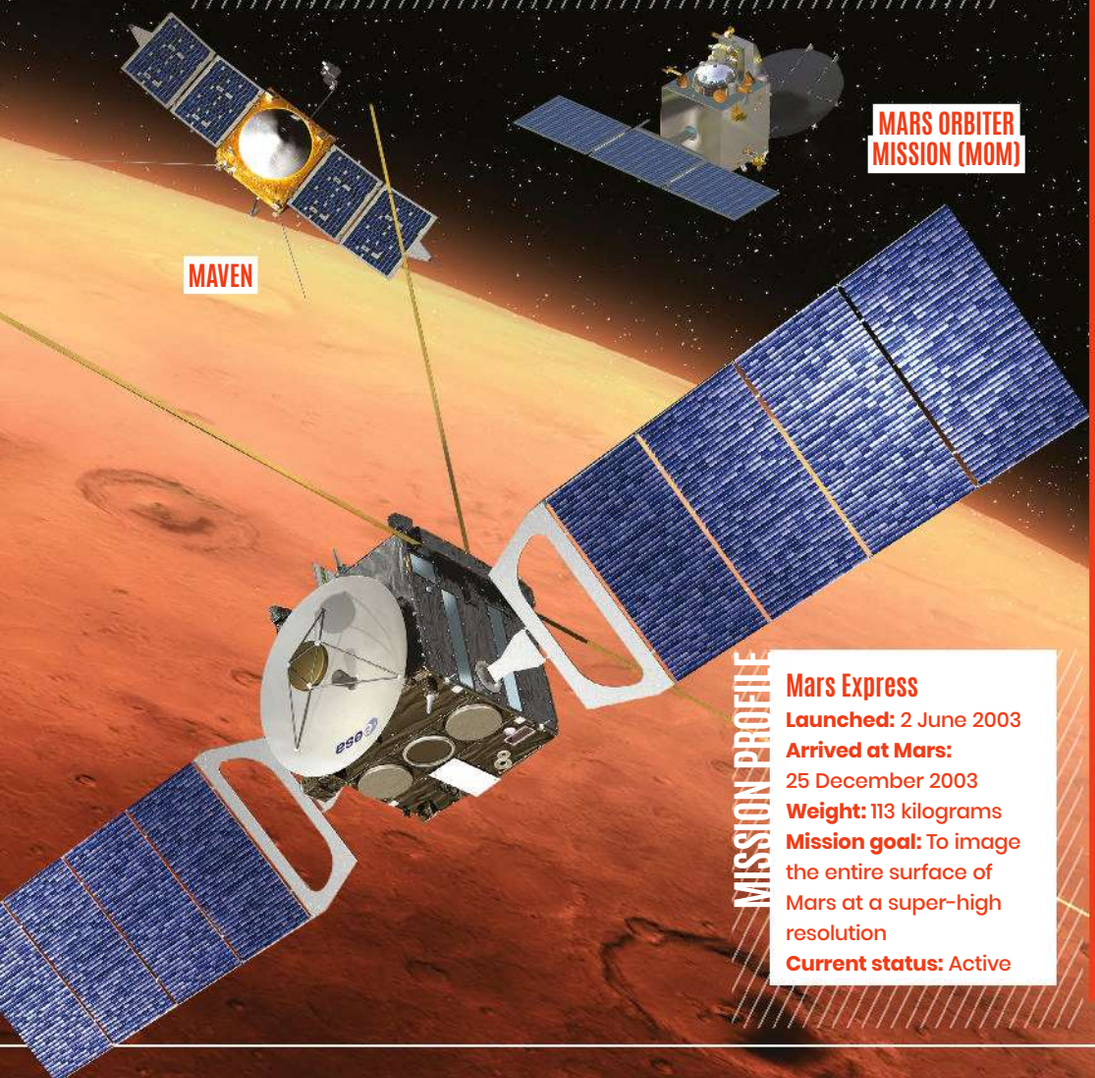
Comet C/2013 A1 (Siding Spring) was discovered in January 2013. In October 2014, it passed within 139,500 kilometres (86,680 miles) of the surface of Mars, just under a third of the distance from Earth to the Moon. At the time there were two active rovers on the surface of the planet – Opportunity and Curiosity – and five active orbiters. All pointed their cameras in its direction. The dust from the tail of the comet could easily have damaged the orbiting spacecraft, so the active orbiters, Mars Express, the Mars Orbiter Mission, Mars Odyssey, the Mars Reconnaissance Explorer and MAVEN, waited on the opposite side of the planet. The comet passed without incident, and four orbiters managed to take pictures as it went by.

Comet Siding Spring gave Mars a spectacular show as it passed nearby in October 2014

17 DUST STORMS CAN SHROUD THE ENTIRE PLANET

The dust that covers the surface of Mars is as fine as smoke and can float even in the painfully thin atmosphere. The biggest dust storm ever recorded on the Red Planet was seen by Mariner 9 when it arrived in 1971. Since 1997, the Mars Global Surveyor has been in a polar orbit around Mars, tracking the weather. As the ground heats up in the morning each spring, dust devils begin to form. Energy from the Sun is absorbed by the dust and rocks, and in turn starts to heat the gases. They then rise up through the cold air, creating a spinning vortex. NASA says that the atmosphere is so thin that you wouldn't feel much wind on Mars, but that the fine dust whips through the air, building up static and releasing electrical arcs. As the day cools the storms subside, but the tiny dust particles can fly tens of kilometres into the air. In the low gravity, it takes a long time for them to fall back down to the surface again, with some remaining airborne for months.





MISSION PROFILE

Mars Express

Launched: 2 June 2003
Arrived at Mars: 25 December 2003
Weight: 113 kilograms
Mission goal: To image the entire surface of Mars at a super-high resolution
Current status: Active

18 MARS HAS CARBON DIOXIDE WEATHER

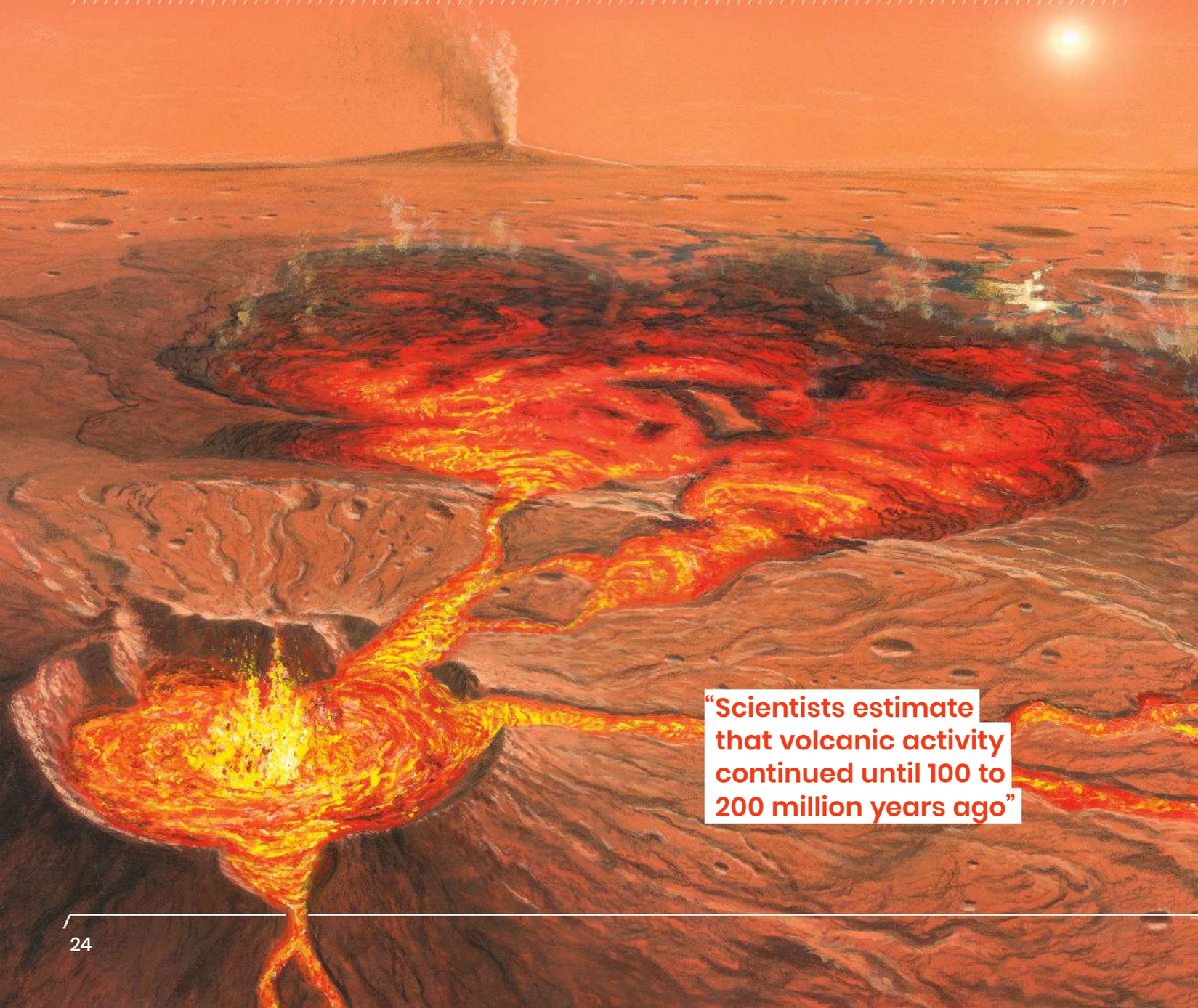
The atmosphere was first analysed during the Mariner 4 flyby, and has been tested by several orbiters since. The first accurate measurements of its composition were made by the Viking landers, revealing that the thin air is 95.32 per cent carbon dioxide, 2.7 per cent nitrogen and 1.6 per cent argon. Just 0.13 per cent of the atmosphere is oxygen, and 0.03 per cent is water vapour. The atmosphere on Earth is 78 per cent nitrogen, 21 per cent oxygen and just 0.04 per cent carbon dioxide.

The ESA launched Mars Express in 2003, and it's been monitoring the atmosphere ever since. It has observed carbon dioxide clouds forming around 80 kilometres (50 miles) in the air above the equator and watched as it freezes down to cap the poles each winter. The orbiter also detected traces of methane gas alongside water vapour, sparking scientific interest in the potential for volcanic activity, or even life, beneath the surface.

© NASA; Alamy;

19 THERE HAS BEEN RECENT VOLCANIC ACTIVITY ON MARS

The history of Mars is mapped out in the rocks that cover its surface, and using data gathered from orbiters and landers, scientists are beginning to piece together the planet's past. Over time, conditions on the surface have changed dramatically. The Mariner 4 spacecraft observed some of the planet's oldest regions – craters made in the southern hemisphere during the heavy bombardment that battered the rocky planets around 4 billion years ago. Although this part of the surface has remained largely unchanged, the rest of the planet has since been remodelled. The northern hemisphere is much less cratered and has been covered with smooth lava plains, and the tops of the shield volcanoes at the equator indicate that they were recently active. Lava flows from the volcanoes repeatedly covered up impact craters, and by looking at the calderas at the tops of the mountains it's possible to estimate when they last erupted. Mars Express has been examining the volcanoes, and scientists estimate that volcanic activity continued until 100 to 200 million years ago, with evidence of lava flows within the last few million years. It may be that the volcanoes are dormant, not extinct.



"Scientists estimate that volcanic activity continued until 100 to 200 million years ago"

20 TRAVELLING TO MARS IS EXTREMELY CHALLENGING

If there's one thing we've learnt about Mars over the last 50 years of space exploration, it's that travelling to the Red Planet is incredibly difficult. The first flyby in 1965 was the seventh attempt at reaching the planet, and since then, several more orbiters and landers have been lost. In the 1990s, four of NASA's six missions to the Red Planet failed. In 2003 the ESA lost the Beagle 2 lander launched alongside the successful Mars Express.

Those that did reach the Red Planet had problems of their own. Although the Phoenix lander outlasted its three-month mission, its solar panels were eventually destroyed by the weight of dry ice during the winter. After six years on the surface, a wheel on NASA's Spirit rover stopped working, causing it to become irrevocably trapped in the Martian sands in 2009. NASA's Curiosity rover experienced unexpectedly quick damage to its aluminium wheels, forcing scientists to drive it in reverse. But despite all these problems, we've learnt a huge amount about Mars, and the combined information from both the successes and failures is being assembled and used to inform current and future missions. Using the information we've acquired, NASA intends to take humans to Mars in the 2030s.

21 THERE ARE CAVES ON MARS

In 2007, the infrared cameras of the Mars Odyssey orbiter spotted a set of caves on the surface, dubbed the Seven Sisters. They're located on the side of one of the shield volcanoes, Arsia Mons, and are visible as 'skylights', extending tens of metres downwards into lava tubes. Caves on Mars could provide easier access to buried layers of ancient rock without the need for heavy-duty drilling. These sheltered areas might be a good place to search for evidence of past life on the planet.

22 GAS JETS SPRAY FROM THE SOUTH POLE EVERY SPRING

The Mars Reconnaissance Orbiter, launched in 2001, revealed that as the temperature rises in the spring, the dry ice covering the south pole begins to sublime. Pockets of heated gas explode outwards as jets, throwing dust into the air and creating dark spider-shaped marks on the surface of the planet.

23 SUNSETS ARE PURPLE ON MARS

Viking 1 returned the first images of the Martian sunset in the 1970s. The fine red dust particles tint the sky a pinkish colour in the evening, but as the Sun starts to dip below the horizon, blue light is scattered, creating a purplish hue.

24 MARS HAS OZONE LAYERS

Mars Express has been circling the planet since 2003, and is equipped with an ultraviolet spectrometer. It's shown that Mars has an ozone layer at an altitude of 30 kilometres (19 miles), another in the northern spring and summer at between 30 and 60 kilometres (19 and 37 miles) and a third above the south pole in winter at around 40 to 60 kilometres (25 to 37 miles).

25 MARS HAS TWO SATELLITES

The two moons of Mars are named Phobos and Deimos after the sons of the Greek god of war, Ares. Phobos has the closest orbit of any known moon, passing within 6,000 kilometres (3,730 miles) of the surface of the Red Planet and completing a full circle three times a day. They've been photographed by several missions, but never visited.

© NASA; Science Photo Library;

SHAPESHIFTING SPACECRAFT

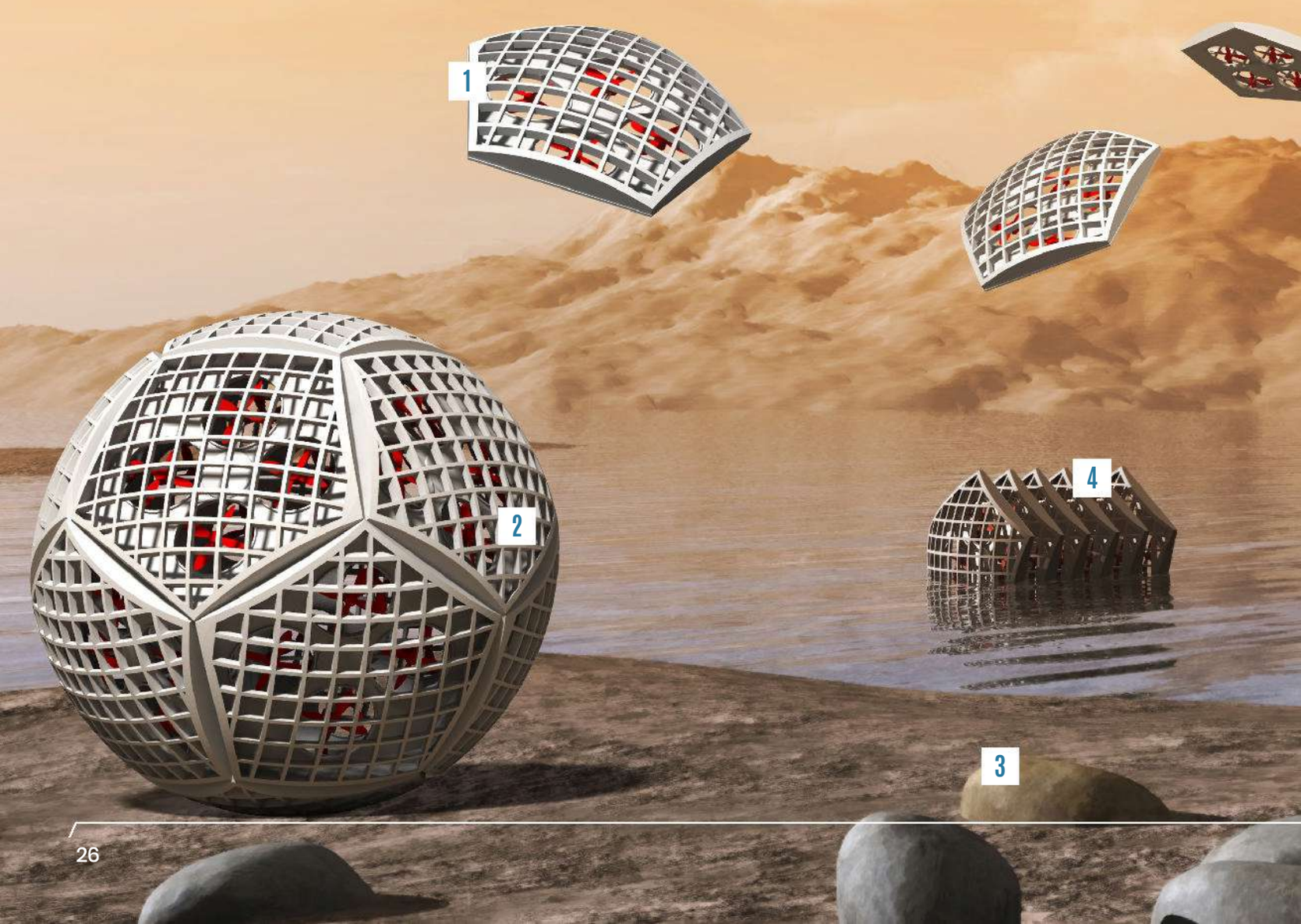
Futuristic robotic explorers could seamlessly switch between swimming and spelunking

A team of scientists and engineers at NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California, are devising a concept mission which could see a swarm of mini-robots exploring worlds beyond our own – and top of the list is Saturn's moon Titan. This swarm will be like no other mission before it, as it will consist of a team of up to 12 robots that can morph into different shapes to help them roll, fly, float and swim. This team of robots has appropriately been named 'Shapeshifter'.

When NASA's Cassini mission flew past Titan and dropped the European Space Agency's Huygens probe onto the surface, it revealed a world of lakes, rivers and oceans – flowing with liquid ethane and methane instead of water – as well as volcanoes spewing out ammonia and water, also known as 'cryovolcanoes'. Earth also exhibits oceans, volcanoes and other features carved out by liquids, as well as ethane and methane. This resemblance between Titan and Earth has scientists itching to return to the Saturnian moon to explore further.

The NASA Innovative Advanced Concepts (NIAC) Program provides an important platform for creative ideas to come to life. In this case, the project has allowed scientists at JPL to scrutinise the idea of exploring Titan in a truly original way. By exploiting the moon's thick atmosphere and low gravity, flying is the favourable mode of transport. But what if you don't have to be restricted to flying?

JPL principal investigator Ali Agha and his colleagues at Stanford and



Cornell universities are envisaging a swarm of mini-robots, called 'cobots', that can float around in Titan's hydrocarbon lakes, morph into a ball so they can roll across the surface and can morph once again into drones, where propellers will send them gliding through the atmosphere.

"We have very limited information about the composition of the surface: rocky terrain, methane lakes, cryovolcanoes... we potentially have all of these, but we don't know for certain," said Agha. "We thought about how to create a system that's versatile and capable of traversing different types of terrain, but also compact enough to launch on a rocket."

The Shapeshifter swarm will arrive at the moon on board a 'mothership'. Similar to the Huygens probe, the mothership will touch down with the help of a parachute, carrying a scientific instrumental suite to provide an in-depth analysis of the surface. At the same time it will provide an important pit stop for the cobots as an energy source. The cobots will return the favour by transporting the mothership via the medium of flight. Agha predicts that it would take about ten cobots to move the mothership.

In terms of production, the Shapeshifter concept mission is very much in its early stages. Engineers at JPL have created prototypes that are being used to demonstrate the feasibility of semi-autonomous robots capable of morphing in shape. A 3D-printed prototype that is currently being used to explore the backyard of JPL is essentially a drone caught inside a hamster wheel – it has propellers encased within two halves of a wheel. After splitting into their respective halves, the drones could then transition from surface-rolling to aerial exploration.

1 Sticking in formation

When they explore caves, called spelunking, the cobots can form a chain to maintain communication with the surface.

2 Stop, pop and roll

When exploring the surface, cobots will pop out into a ball, which will then roll across the surface in a way that conserves energy.

3 The transporter

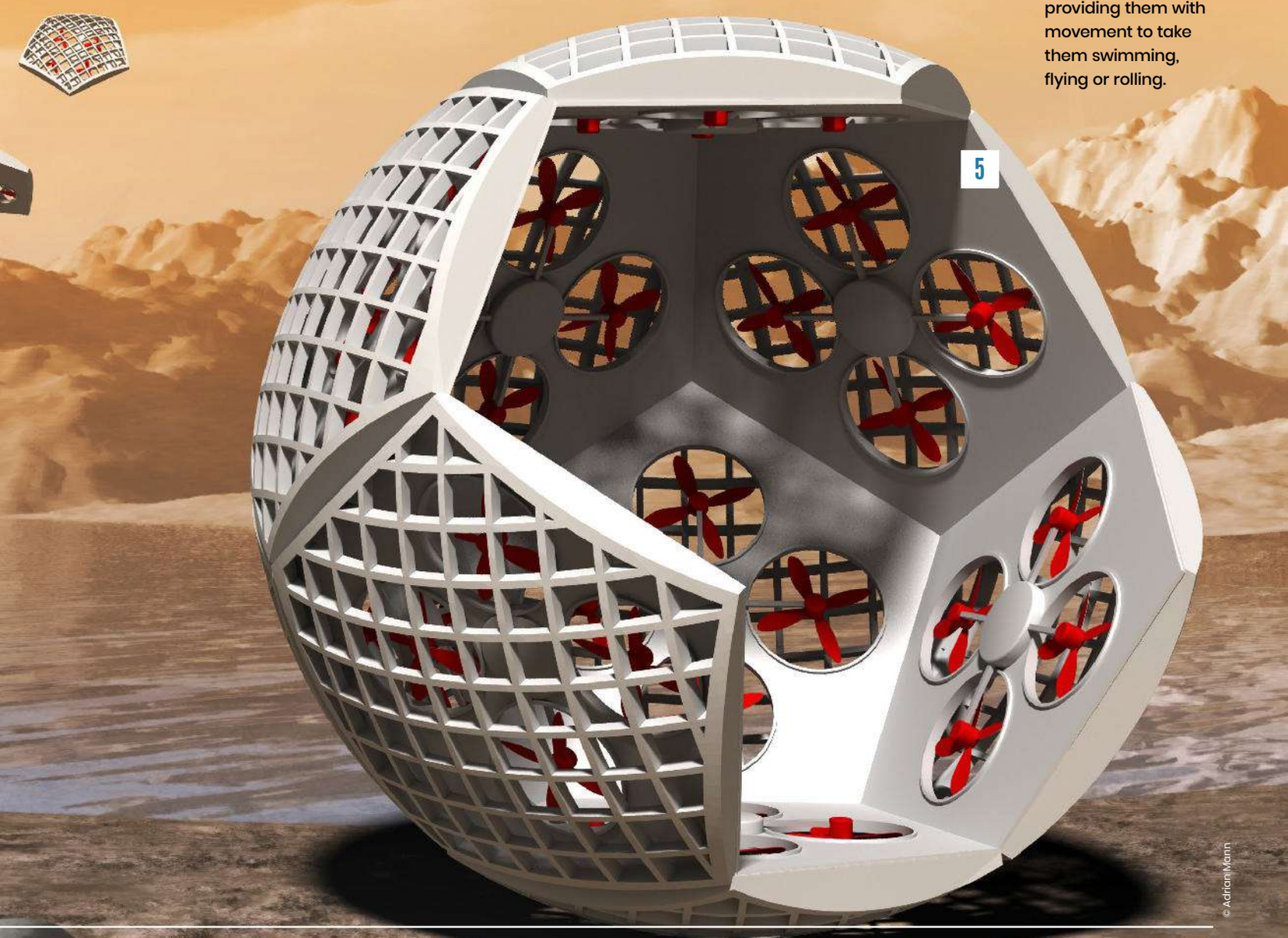
This robotic team will also be used to transport large and heavy objects, including the Shapeshifter's 'mothership' lander.

4 Torpedo shape

In order to swim through liquids, the cobots will take a torpedo-like shape. This will allow for a more efficient mode of under-liquid movement.

5 The engine

Each cobot has propellers, providing them with movement to take them swimming, flying or rolling.



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BIO+

Nick Sagan

As the son of acclaimed astronomer and science populariser Carl Sagan, it was always inevitable that Nick Sagan would have a strong link to space. Aged just six, he recorded a greeting for the Golden Record placed aboard both Voyager spacecraft in 1977 – should intelligent life come across it, they'll hear: "Hello from the children of planet Earth." As an adult he has written books and screenplays, developed video games and produced TV specials, most of which are strongly associated with science fiction. His sci-fi novels include *Idlewild*, *Edenborn* and *Everfree*.

© EMEA, Alamy

Carl Sagan exclusive

"Dad was one of the greatest teachers ever"

Although Nick Sagan didn't follow in the footsteps of his father, astronomer Carl Sagan, his novels, TV shows, movies and video games have clearly been influenced by his love of space

Interviewed by David Crookes

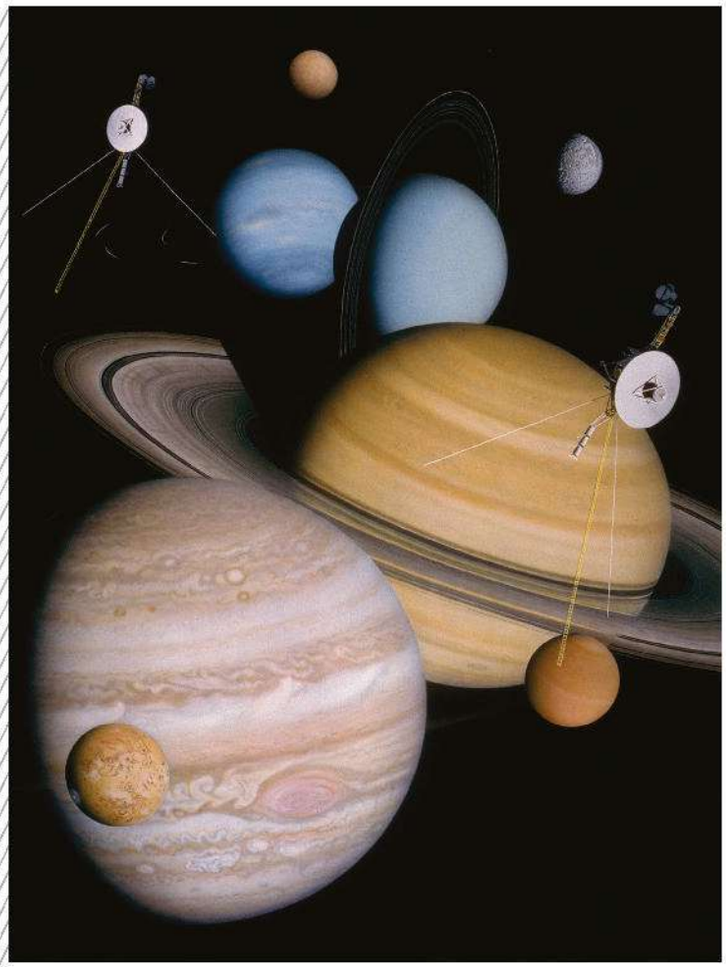
As a child, were you aware you had a famous father?
There were certain signs that were hard to ignore. When I was in elementary school they would show episodes of *Cosmos* in both my science and social studies classes, and I would sit there watching my dad talking to us on TV. I also had a very nice, if strange, upbringing where scientists and science-fiction writers would come to the house and we'd go to rocket launches and all that kind of stuff. But none of this seemed peculiar to me and it just seemed to be what the family did. It was only later when I realised my upbringing was surreal. At the time it was normal.

Would your father try to engage with you about space? If so, were you actually interested?
I was fascinated, but then I should say that I was also rather spoiled because my dad was one of the greatest teachers ever. He was so giving of his time, and truthful. Whereas a lot of parents who get a question they don't know may try and fudge something to make it sound plausible or say, "I don't know kid, go look it up," he would be honest. If there was something he didn't know the answer to – which I have to say was rare – then he'd say, "that is a great question and maybe you'll be the first to discover the answer". That was very sweet, loving and honourable.

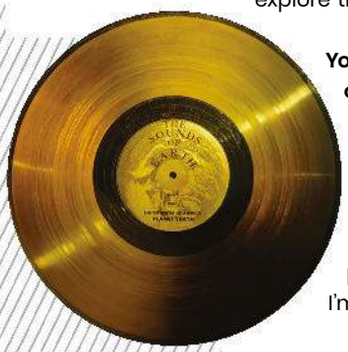
It's fair to say that your father has had a massive impact on your life?
Absolutely. My dad was a scientist and my mother a writer, and I have taken the professions of both parents and kind of weaved them together. But also, when I was a kid my dad introduced me to some of the grandmasters of science fiction, such as Edgar Rice Burroughs. He read me the *A Princess of Mars* series as a child and I just devoured those little paperbacks as a kid. I'm sure that had a major effect on me too.

Had you ever considered following your father in exploring astronomy or science?
I did, but science is challenging. While I love it and I love the humility at the heart of the scientific method, my brain doesn't

Nick made *Alien Encounters* in cooperation with the SETI Institute, which was founded by his father in the early 1960s



Nick's voice has now passed by all of the planets and moons of the outer Solar System



Two phonograph records containing sounds from Earth – including a message from Nick Sagan, aged six – were put on board the Voyager spacecraft

necessarily bend that way. I was thrilled to get an A in a college astronomy class – that was by far my top achievement there – but I admire and to a certain extent envy people who have the minds that allow them that kind of path. I've never seen myself following in his footsteps. It would be like trying to be a successful baseball player when your father is Babe Ruth: how do you top that? I like this combination I pursue where I take the big questions behind a lot of the science that he did and explore them in different ways.

You never felt a weight of expectation?

To his credit, my dad never pushed me into astronomy at any point. He just wanted me to find my own path and be happy and productive, and I never felt pressured to become a scientist. I'm very grateful for that.

You pitched ideas for *Star Trek* and ended up working on some of the episodes. Was your interest in science fiction sparked by being surrounded by science fact?

I'm sure it was a mix of things, but there are also different kinds of science fiction. Hard sci-fi is scientific; it'd look at how a warp engine might work or explore the physics of time travel. Social science fiction raises significant questions about humanity and our species: how did we get started, where are we going, what's it all about, do we carry the seeds of our own destruction within us and so on. That's where my heart lies. While I was influenced by my dad's planetary science, I think I was influenced by the science-fiction writers he introduced me to. I also grew up watching the original Star Trek and fell in love with those episodes.

You also co-wrote a book that looked at how science fiction had impacted on real-life technologies and ideas. How did that come about?

There's a wonderful reciprocal relationship between science and science fiction that doesn't get talked about quite as much as it should. Often a scientist will create something or advance some area of knowledge that science-fiction writers will take inspiration from, and that in turn would inspire other scientists. There are people out there designing robots who were inspired by R2-D2 and C-3PO. If you go back in time you'll find the father of modern rocketry, Robert H. Goddard, and see that he sent fan letters to H. G. Wells about how much he loved *War of the Worlds*, talking about how we would actually get to Mars and all of this kind of stuff. You see this really fascinating and wonderful relation that serves a useful purpose in society where fact and fiction work hand in hand to either imagine a better future, or at least warn against the consequences of where we might go if we're not careful.

Is that blurred line of interest one of the reasons why your two-part *Alien Encounters* series mixed science-fiction drama with commentary from scientists such as Neil deGrasse Tyson?

It's tricky because you do get people who feel like we're mixing things that shouldn't be mixed, but at the same time there's a real opportunity to do something fascinating. With *Alien Encounters*, we were able to present a fictional scenario and then have scientists talk about the possibility of it happening, what it would mean and the larger questions. I think it worked well, and I don't think anyone was confused about it.

Was it the same approach for *The Searcher*, which was shown at the Adler Planetarium in 2011?

Yes. That was particularly meaningful to me because my dad went to the University of Chicago, so the idea of creating a show for a planetarium that he visited many times as a college student resonated. This story involved an extraterrestrial who effectively commandeers a planetarium show and leads us on an adventure looking for his lost people. We visited different astronomical phenomena along the way, and I found the planetarium to be a nice engine to take us to those wonderful places. But what we also felt was that there were certain things that were scientific fact that planetarium show viewers might have thought was

science fiction. For example, there's a whole segment on colliding galaxies and how the Andromeda Galaxy is going to collide with the Milky Way at some point in the distant future, and people thought that it was fiction. When you're blurring the lines, you need to make sure people understand what's real and what's not.

Given your work involving aliens, does the potential for life elsewhere fascinate you?
It's one of the biggest questions we can think to ask, and it goes back to the very heart of our origin. What I find fascinating is that my dad, back in the 1960s, put out a possibility that there might be life in the clouds of a planet as inhospitable as Venus. And in the past few years there have been advances in science suggesting that it actually might be a realistic possibility, with scientists saying we should check the clouds to see if it's true. It's staggering to me that in all these years after his death he continues to be involved at some level in the search for life.

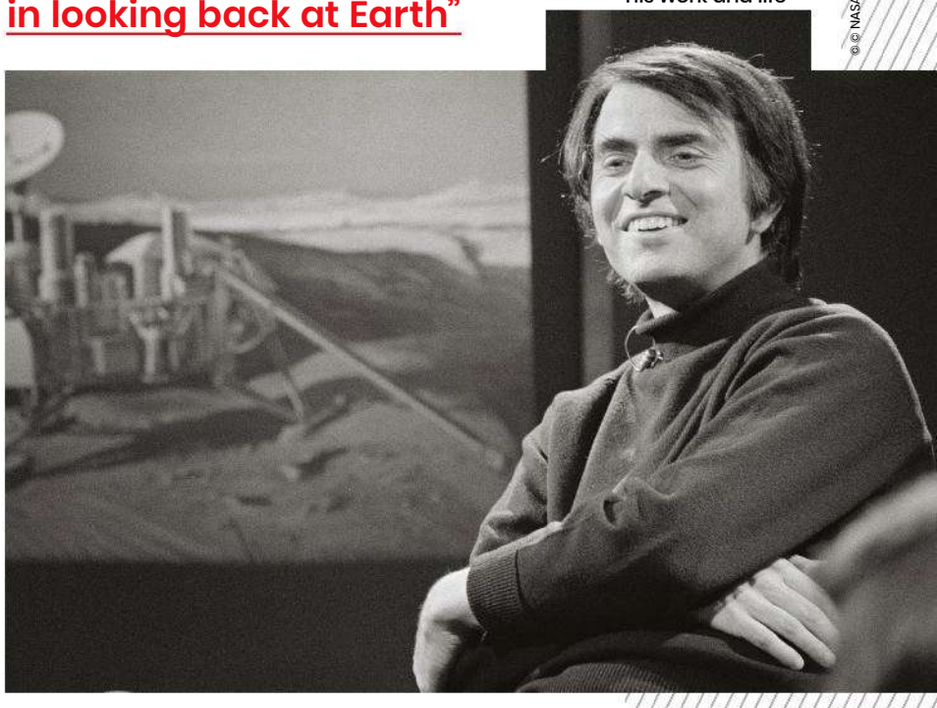
Do you keep up to date with the efforts to find extraterrestrial life?
Absolutely. I'm fascinated by the idea of panspermia and the potential that life on Earth could have originally come from the ice of the comets that impacted our planet, but I'm also interested in what this would mean: we'd learn so much more about our story if we could find that we're not alone. I'm also intrigued by the Drake equation – the suggestion that the universe should be teeming with life. I have a deep, lonely, longing feeling about such matters and I very often wonder if the reason we haven't found extraterrestrial life is because intelligence evolves to the point where it takes over a planet, only for the same skills to work against a species. Do species simply blow themselves up when they get increasingly powerful technology, and is that why we haven't heard from anyone out there? If that's the case, then what a lesson that is for us to be careful. But then, as my dad would also say, if we are in a strange, unlikely scenario where we're unique, then it makes it even more important for us to treat each other with great kindness and reverence. Don't harm a human because there's a chance you won't find another one anywhere else in the universe.

When you look at the possibilities today, such as space travel, is it an exciting time?
If we don't blow ourselves up then we're at the dawn of an amazing new era where we could begin to not only dip our toes in the vast cosmic ocean, but start to truly reach out to species. I remember Stephen Hawking talking about the need for us to establish an off-world colony, ideally within the next hundred years, the idea being that we should not keep all of our eggs in one basket and instead take an opportunity to safeguard the species by having people in different places. I find something deeply poignant about that. There's this amazing universe here and we're just now discovering the ability to practically reach out. Soon we will be able to figure out how to either terraform or set up a long-lasting future and live on a previously uninhabitable world.

Is that desirable?
At the same time, it's unlikely that we're going to find anywhere else in the universe that's more suited for life on Earth than Earth. We've evolved to enjoy this planet, and as much as the excitement over the possibility of space travel appeals to me and appeals to many people, I think it's a huge mistake to ever view Earth as some kind of disposable starting point. It may well be that we'll have to fan out and find new digs, but we really need to appreciate where we started.

Would you be interested in going to space?
I missed my window. I'm not sure I'd pass the astronaut fitness candidacy. But having said that, yes, as an intellectual exercise I would love to go. It would be amazing to have that famous experience that so many astronauts have in looking back at Earth and seeing the planet outside of yourself. People who have done this talk about this amazing spiritual feeling that passes through them, and just for that reason alone I would love to go. I'd also like to experience life on a space station. It's something I've always thought about and wondered what it would be like.

"It would be amazing to have that famous experience that so many astronauts have in looking back at Earth"



Nick Sagan didn't become an astronomer like his father, but space is a huge influence in his work and life

© © NASA/JPL; CBS Photo Archive / Getty; Adler Planetarium

FOCUS ON

A BREAKTHROUGH SIMULATION MAY UNITE QUANTUM PHYSICS AND GENERAL RELATIVITY

It could suggest a way to study 'quantum gravity', the missing link between quantum physics and general relativity, in a laboratory

Reported by Robert Lea

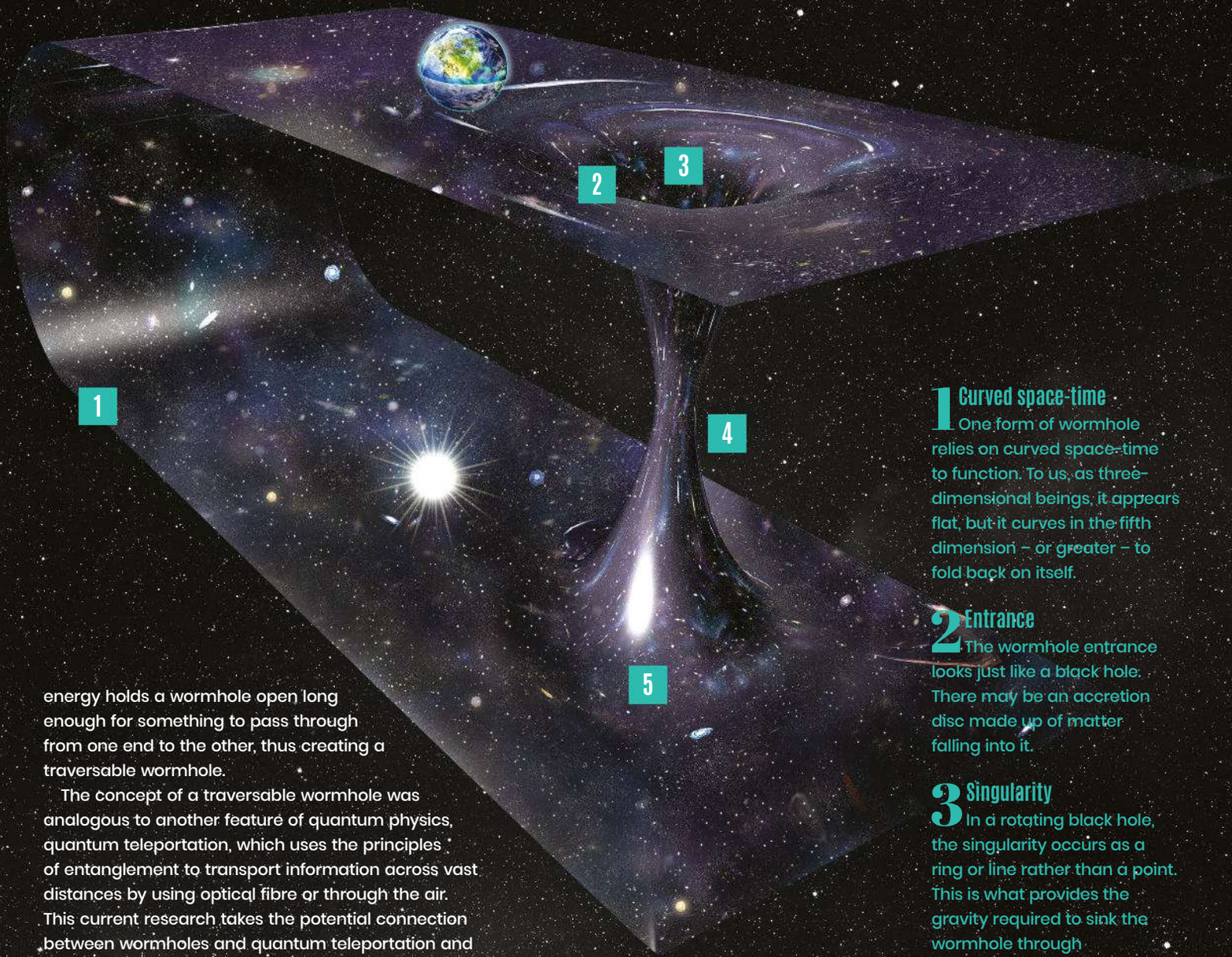
A new quantum experiment allows scientists to study the dynamics of wormholes, theoretical space-time entities that first emerged from general relativity. Rather than creating an actual wormhole, a rip in time and space that's theorised to form a bridge between one distant region of space and another, the team built a wormhole model to run on a quantum processor. This allowed them to investigate the physics of wormholes and their potential connection to so-called 'quantum gravity.'

"We found a quantum system that exhibits key properties of a gravitational wormhole yet is sufficiently small to implement on today's quantum hardware," Quantum Communication Channels for Fundamental Physics (QCCFP) principal investigator Maria Spiropulu said. "This work constitutes a step towards a larger program of testing quantum gravity physics using a quantum computer." Samantha Davis, a graduate student at the California Institute of Technology, said that it took "a really long time to arrive at the results". The team was surprised by the outcome, which suggests that wormhole-like behaviour can be explained from the perspective of both quantum physics and general relativity. Spiropulu added that while this new model doesn't substitute for direct probes of quantum gravity, it does offer a powerful way to investigate ideas of quantum gravity in the lab.

General relativity is the best description scientists have of the universe on truly massive scales, while quantum physics is the most accurate picture of the subatomic world. The problem is that these two fields of physics don't unite. This is because there is no description of gravity on the scale of quantum physics, and gravity is the primary concern of general relativity. That makes the discovery of a 'quantum theory of gravity' a pressing concern for physicists and the key to a long-sought-after 'theory of everything' in physics. The team's quantum-created wormhole could be a step in the right direction in this quest.

Scientists have been theorising about wormholes ever since 1935, when Albert Einstein took his 1915 equations of general relativity and, together with American-Israeli physicist Nathan Rosen, described them as tunnels through the very fabric of space-time. Acquiring the moniker of 'Einstein-Rosen bridges', these space-time tunnels were later named wormholes by black hole expert John Wheeler in the 1950s.

In 2013, a connection was forged between wormholes and entanglement, the element of quantum physics that suggests two particles can be linked in such a way that changing one instantaneously changes the other, no matter how far they're separated, even if they're located at opposite sides of the universe from one another. Physicists Juan Maldacena and Leonard Susskind linked the two disparate worlds of general relativity and quantum physics when they theorised that wormholes were equivalent to entanglement in that both described a connection between distant areas of the universe. "It was a very daring and poetic idea," Spiropulu said. In 2017, the idea put forward by Maldacena and Susskind was expanded upon by Harvard University physicist Daniel Jafferis, the co-lead scientist of this current research, and his colleagues. They developed a concept in which negative repulsive



energy holds a wormhole open long enough for something to pass through from one end to the other, thus creating a traversable wormhole.

The concept of a traversable wormhole was analogous to another feature of quantum physics, quantum teleportation, which uses the principles of entanglement to transport information across vast distances by using optical fibre or through the air. This current research takes the potential connection between wormholes and quantum teleportation and explores it in greater detail as the Spiropulu-led team performs the first experiments that probe the idea that information travelling from one point in space to another can be described either using the language of gravity established by general relativity or by quantum entanglement – the language of quantum physics.

The team started work by developing a Sachdev-Ye-Kitaev (SYK) quantum system and entangling it with another SYK system, resulting in a model built to preserve gravitational properties. This model was then reduced to a simplified form with machine learning on conventional computers, after which the scientists could observe wormhole-like dynamics on Google's Sycamore quantum processor. "We employed learning techniques to find and prepare a simple SYK-like quantum system that could be encoded in the current quantum architectures and that would preserve the gravitational properties," Spiropulu said. "In other words, we simplified the microscopic description of the SYK quantum system and studied the resulting effective model that we found on the quantum processor."

In the experiment, the team introduced a qubit, the basic unit of quantum computing – equivalent to a standard bit in traditional computing – to one of the SYKs. They then watched as information emerged at the other SYK. This meant that the information had travelled from one quantum system and emerged from another via quantum teleportation in the language of quantum physics. In the language of gravity, however, this replicated a journey through a traversable wormhole.

The key characteristics of a traversable wormhole were only manifested when the team attempted to prop open their model of a bridge in space-time using pulses of repulsive negative energy. This reflects how real wormholes are expected to behave in the depths of space if they are ever found to exist.

1 Curved space-time

One form of wormhole relies on curved space-time to function. To us, as three-dimensional beings, it appears flat, but it curves in the fifth dimension – or greater – to fold back on itself.

2 Entrance

The wormhole entrance looks just like a black hole. There may be an accretion disc made up of matter falling into it.

3 Singularity

In a rotating black hole, the singularity occurs as a ring or line rather than a point. This is what provides the gravity required to sink the wormhole through space-time.

4 Exotic matter

Keeping the wormhole open against the gravitational forces causing it to collapse requires some negative energy, or anti-gravity, we have yet to discover. Quantum effects within curved space-time may be able to violate the averaged null energy condition, keeping it open.

5 Exit

The exit looks the same as the entrance. Unlike a black hole, from which nothing can escape, forces and even matter may be able to exit from a wormhole.

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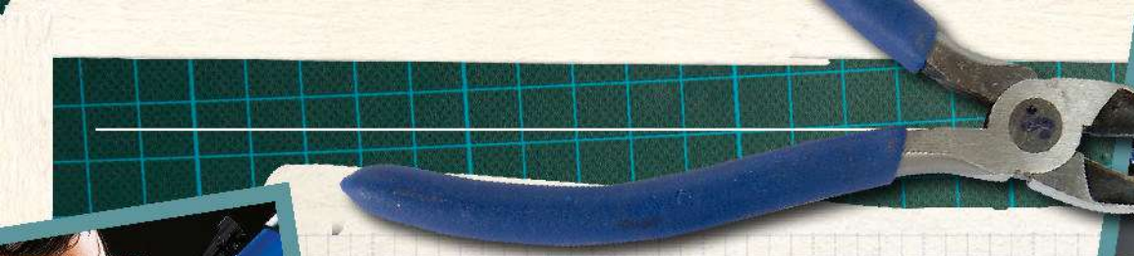


DIY SPACE PROJECTS

Have some spare time on your hands? Check out these activities that can be done at home

You don't have to be a space agency engineer to combine space science and craftsmanship. These projects produce some amazing results with dedication, some elbow grease and a fair amount of free time. Labelled either 'easy' or 'expert', these projects will be sure to keep you busy, especially the 'expert' ones. Each project is excellent in combining a love for astronomy and space exploration with a hands-on approach. You can go from making your own model of the famous Saturn V rocket, the rocket that launched the first humans to the Moon in 1969, to firing a powerful laser at the Moon to confirm how far away it is.

None of these projects can be done with items found just lying around the house, so you'll need to make a checklist for your desired activity and gather materials. Everyone loves a challenge, and the harder projects are always the more rewarding. If you follow these guides, along with our recommended 'for more information' sites, you can create a masterpiece.

1 MAKE YOUR OWN TELESCOPE

EASY

The simplest option here, this DIY telescope is quicker and easier to make than the other projects. With a simple selection of materials and tools you can create your own sliding telescope, probably best suited as an educational tool. Although it can't provide a decent enough focus to delve into the true sights of the night sky, it's an excellent educational experience for a youngster or beginner. The general workings of a reflector telescope can be learnt, such as light focusing, and if this project takes your fancy then you could try a more advanced version.

For more information

Watch Canada Science and Technology Museum's video, 'How to Build a Telescope', at: **youtube.com/watch?v=uZeF1KETaU4**

1 Materials checklist

The list of materials and tools needed is simple, containing mostly household items. In order to make your own telescope you must have a large piece of black Bristol board, a glue gun, a stapler, black electrical tape, a pair of scissors, a cardboard tube and two magnifying glasses – ideally one should be bigger than the other.

2 Assembling the tubes

Cut three black Bristol board sheets – two to fit around the cardboard tube and one twice the length. Glue the smaller sheets around and within the cardboard tube, and place the longer sheet in the tube, stapled at its ends, glued and wrapped in electrical tape to secure it while still allowing it to slide in and out properly.

3 Affix the lenses

The larger lens should be glued to the top of the cardboard tube and secured with electrical tape. At the other end of the telescope, the second lens should be fixed to the end of the slider tube, similar to the first lens. The sliding focus lens will concentrate the light from more distant objects to suit your eyes.

4 Finishing touches

Once the telescope is complete, some final decorative touches can be added. Taking some crayons, or coloured chalk, you can draw some constellations on your telescope, depending on your personal preference. Now everything is in order to give your new telescope a test run and see what sights are at your disposal.

© NASA; Nicholas Forder; Canada Science and Technology Museum/YouTube

2 BUILD A MISSION CONTROL DESK

EXPERT

This household Mission Control desk is a great way to get more involved in space. Not only is it visually stimulating, but there are buttons and authentic sounds. It can also be folded away and used as a normal desk for when work needs to be done. This project requires a fine craftsman and access to machinery such as drills, saws and sanders.

This project requires a lot of woodwork and wiring, but upon completion it will be a great representation of what it's like being at NASA's Mission Control Center, experiencing what real Mission Control personnel have gone through during a mission.

For more information

Check out *Make* magazine's extensive how-to guide, 'How to Build a Mission Control desk', at **makezine.com/projects/mission-control-desk**

3 BUILD YOUR OWN SATURN V MODEL

EASY

Revell has a model of the Saturn V for £29.95 (€34.99). All that's needed to make it is glue, paint, paintbrushes and a fine hand. The full model kit includes all the stages and a launchpad, a booklet of building instructions and decals. For a smooth and safe assembly, please be sure to read through the instruction manual before tackling the task. A lot of gluing is involved, so the best way to start the project would be to go through the building manual and deduce which minor sections, such as the thrusters, need gluing and need to dry before they can be added to the main structure. The best way to start off is construction of the first stage and its five thruster nozzles.

Next is the assembly of the second stage, equipped with its own set of five thruster nozzles, and the third stage, with a singular thruster nozzle. There's more to this model than just the stages, as it also includes a detailed Lunar Module, the Service Module, the Command Module, an emergency rescue rocket fitted to the nose of the rocket and finally three figurines, which add a real sense of scale. All three stages and the different modules are detachable, which means this model can serve as a good educational tool as well.

After everything is glued and dried, you can start painting. Revell also sells a good-quality series of paints and sets of paintbrushes at reasonable prices. According to the manual, 13 different colours are stated as being used – with it naming all 13 colours required. The model primarily consists of white and black, so it may be worth stocking up on these two colours so you have enough to finish the model.

After the paint has dried, it's time to add the finishing touches in the form of the decals. These labels can be stuck to their designated places on the model rocket, and you can finally marvel at your 77-centimetre (30-inch) model of the Saturn V.

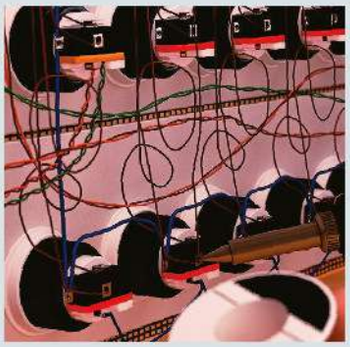
FIND OUT MORE HERE:
tinyurl.com/4yx6w5v9

1 Careful planning

Planning is of the utmost importance when building a control centre replica. You need to weigh up how much room you have to work with, but also how much time and money you wish to invest in this. Depending on the size of your desired desk, the control panel can be designed containing displays, speakers and controls.

2 Construct and wire

This is going to be the most intense section of the project, as it requires the actual construction of the control centre as well as the cutting out, priming, painting and printing of the individual panels. Getting into the more electronic side, the switches and LEDs must be wired safely as well.



3 Adding sounds

Audio files from the Apollo 11 mission can be found online at NASA's Apollo 11 Flight Journal. MP3 files can be downloaded from the website and can be edited using a computer program such as Audacity. This stage also requires some programming, which will help designate the correct switch to the right sound.

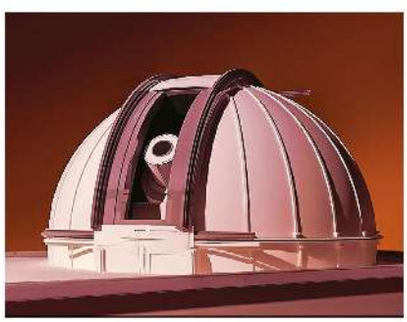
4 Refining the Mission Control desk

In principle, everything should be in place to have your Mission Control centre up and running. However, it may not be perfect the first time around, so we recommend giving it a 'test run'. From this you can tweak any software and hardware that needs it and make any other improvements as you see fit.

EXPERT

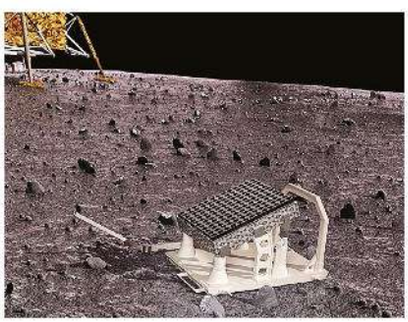
4 FIRE A LASER AT THE MOON

The Moon lies 384,400 kilometres (238,900 miles) from Earth. How do we know that? During the Apollo missions, astronauts placed retroreflectors on the Moon so that powerful lasers can be fired at these mirrors from Earth and be reflected back. Anyone on Earth can confirm the distance to the Moon using a powerful laser and some simple maths. But this isn't a project you can do with a laser-pointer pen. To do this, you need a telescope capable of firing much more powerful photons. It would be worth renting time at a local observatory in order to undergo such an exciting experiment.



1 Finding an observatory

An observatory should have the equipment necessary, and you can get help from an astronomer who has done this before. The experiment will go a lot quicker with their help.



2 Commence firing

With precision and perseverance, you can start firing the laser through the telescope and at the Moon, aiming for one of the retroreflectors left on the lunar surface.

3 Returning photons

If the alignment between the telescope and retroreflector is perfect, then the laser photons will return back to the telescope, go through the optics and hit the sensors.

4 Deducing the distance

By knowing the time taken for the photons to return and that the speed of light is constant at 299,792 kilometres (186,000 miles) per second, the exact distance can be calculated.

© Revell; Nicholas Forder; Make/YouTube

5 LAUNCH A HIGH-ALTITUDE BALLOON

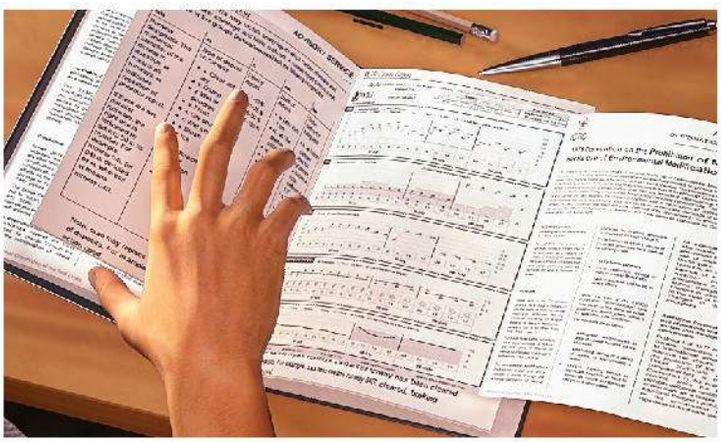
EXPERT

Why would you want to launch a high-altitude balloon? The best answer is that it's the closest you can get to conducting space observations without the launch of a rocket. With plenty of planning and teamwork, this balloon can produce some amazing images while also demonstrating the effects of aerodynamics, physics and other important aspects of science.

Planning is key. Not only does it require a carefully selected array of instruments, it also requires clearance by local authorities, as it could interfere with aircraft. We highly recommend taking great care in your planning to avoid incident.

For more information

Check out Tracksoar's fully informative article at **tracksoar.com/a-tutorial-for-launching-your-first-balloon**



1 Checking regulations

As mentioned above, checking the local regulations and informing the proper authorities about your launch location and time is essential. There are certain requirements for the dimensions and contents of the payload that will need to be taken into account before you launch.

2 Gathering the materials

The essentials are a latex weather balloon, lifting gas and a filler tube, rope to connect the payload, the payload packaging and a parachute. All of these pieces will need to be of good quality to insure maximum protection. The contents of the payload will have to contain a tracker in order to collect the balloon upon landing.

3 Launching the balloon

The launch site must have been chosen as part of the planning process, and you'll need a crew of at least two. We recommend having one person with experience as part of your crew, and someone who is a licensed amateur radio operator if you have an APRS tracker. Once everything is set, you're ready to launch.

4 On its return

When the balloon has reached a high altitude, the payload can start getting amazing snapshots and collecting real scientific data. The average flight time is around three hours, but time will vary depending on the balloon and payload size, among other things. Use the tracker to find your payload once it drops back to Earth.

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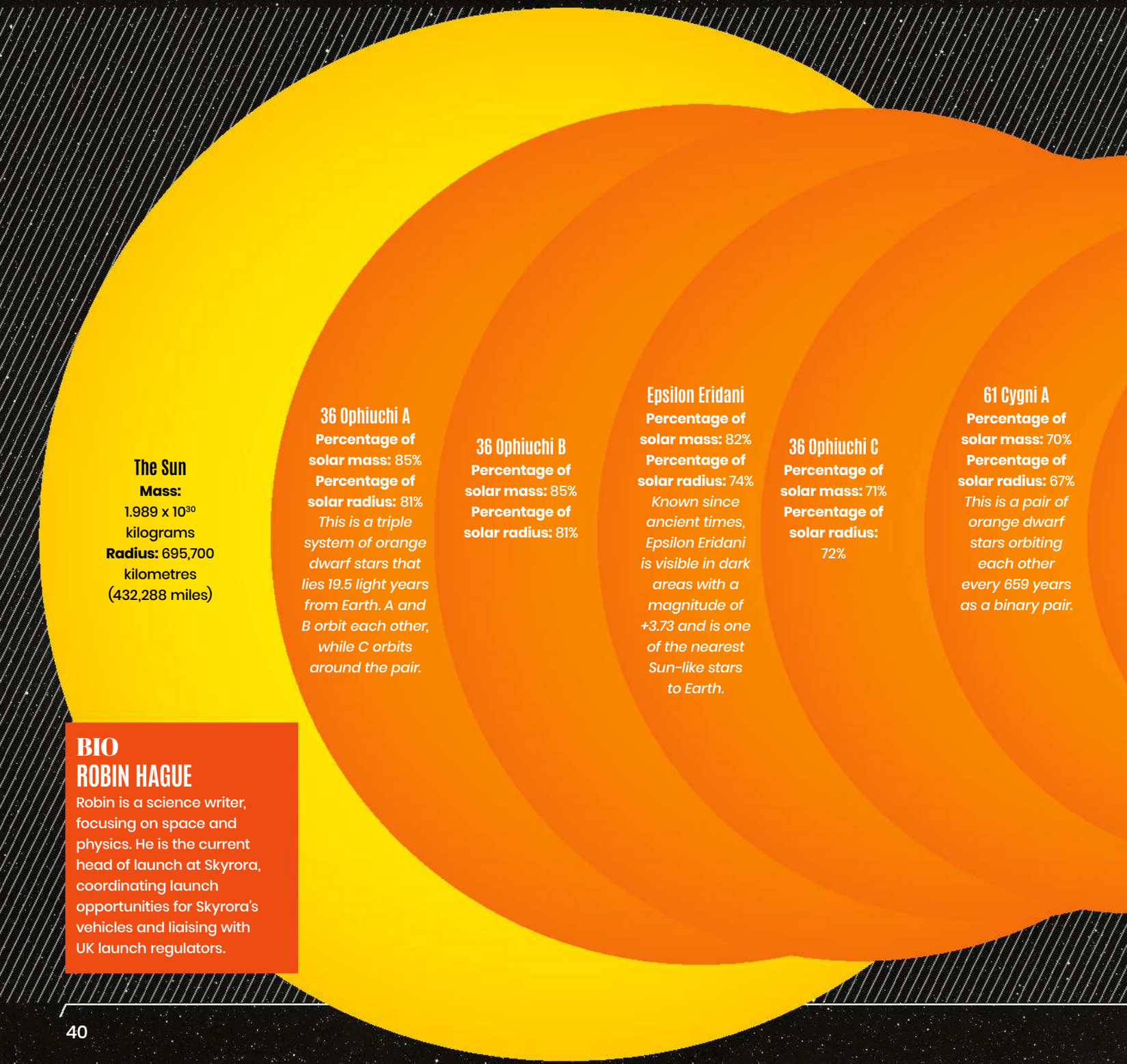
INSTANT EXPERT

ARE DWARF STARS REALLY THAT SMALL?

There are different classifications of dwarf stars, and not all of them are equal

The term 'dwarf star' was first used in the early 20th century by Ejnar Hertzsprung, used in opposition to 'giant star' for two different groups of brightness, rather than very small stars. Now the term is attached to a number of different types of stars, covering the majority of stars in the Hertzsprung–Russell diagram.

The most famous, due to the 2016 detection of the closest exoplanet to Earth around one, are red dwarfs. These appear to be the most common type of star in

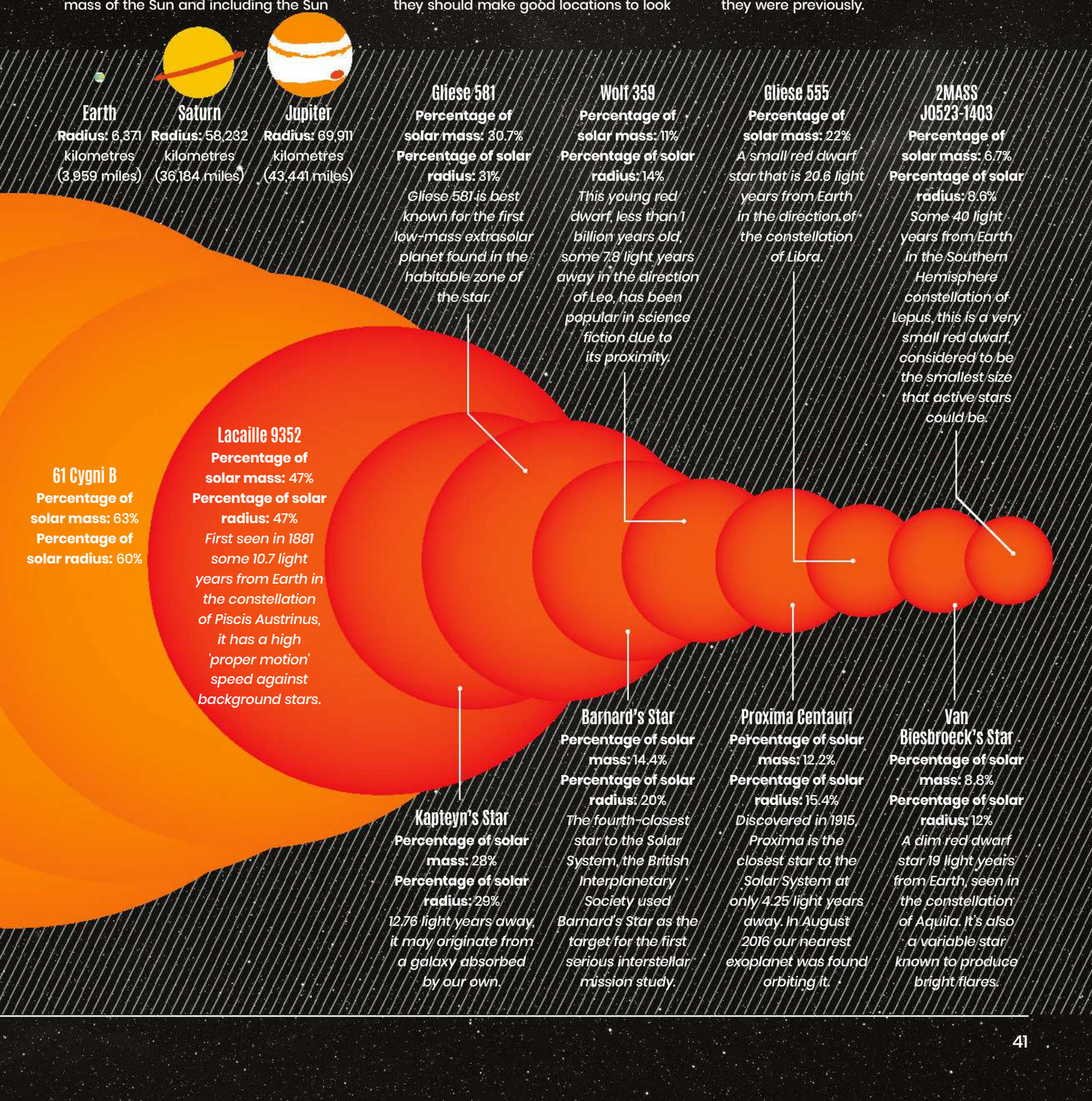

The Sun
Mass: 1.989 x 10^30 kilograms
Radius: 695,700 kilometres (432,288 miles)
36 Ophiuchi A
Percentage of solar mass: 85%
Percentage of solar radius: 81%
This is a triple system of orange dwarf stars that lies 19.5 light years from Earth. A and B orbit each other, while C orbits around the pair.
36 Ophiuchi B
Percentage of solar mass: 85%
Percentage of solar radius: 81%
Epsilon Eridani
Percentage of solar mass: 82%
Percentage of solar radius: 74%
Known since ancient times, Epsilon Eridani is visible in dark areas with a magnitude of +3.73 and is one of the nearest Sun-like stars to Earth.
36 Ophiuchi C
Percentage of solar mass: 71%
Percentage of solar radius: 72%
61 Cygni A
Percentage of solar mass: 70%
Percentage of solar radius: 67%
This is a pair of orange dwarf stars orbiting each other every 659 years as a binary pair.

BIO
ROBIN HAGUE
Robin is a science writer, focusing on space and physics. He is the current head of launch at Skyrora, coordinating launch opportunities for Skyrora's vehicles and liaising with UK launch regulators.

the galaxy, but they're not visible to the naked eye due to their size and brightness. They are small, ranging from 0.075 to 0.5 times the mass of the Sun. They fuse hydrogen into helium and have complete internal convection. Helium is constantly being diffused throughout the star instead of being trapped in the centre, and as a result red dwarfs are likely to be very stable and long-lived.

Yellow dwarf is a term for G-type stars, ranging between 0.8 and 1.2 times the mass of the Sun and including the Sun itself. Although the term is to differentiate them from brighter giant stars, G-types outshine 90 per cent of stars, and are called yellow because of how we perceive sunlight through our atmosphere. They are generally, including our Sun, white in colour because of their temperature. Between the red and yellow dwarfs are orange dwarf stars; these range from 0.45 to 0.8 times the mass of the Sun and are again very stable long-lasting stars, expected to last perhaps three times as long as our Sun. As such, they should make good locations to look for extraterrestrial life, providing a constant habitable zone for planets.

More exotic are white dwarfs; these are a possible end state for large stars that are still too small to collapse into a black hole. They're around the mass of the Sun, but compressed into the volume of Earth, and are composed of a mass of carbon and oxygen that has accumulated in the core of a giant star. They don't have fusion reactions occurring in their material and shine by the residual heat left behind by the active star they were previously.


Earth
Radius: 6,371 kilometres (3,959 miles)
Saturn
Radius: 58,232 kilometres (36,184 miles)
Jupiter
Radius: 69,911 kilometres (43,441 miles)
Gliese 581
Percentage of solar mass: 30.7%
Percentage of solar radius: 31%
Gliese 581 is best known for the first low-mass extrasolar planet found in the habitable zone of the star.
Wolf 359
Percentage of solar mass: 11%
Percentage of solar radius: 14%
This young red dwarf, less than 1 billion years old, some 7.8 light years away in the direction of Leo, has been popular in science fiction due to its proximity.
Gliese 555
Percentage of solar mass: 22%
A small red dwarf star that is 20.6 light years from Earth in the direction of the constellation of Libra.
2MASS J0523-1403
Percentage of solar mass: 6.7%
Percentage of solar radius: 8.6%
Some 40 light years from Earth in the Southern Hemisphere constellation of Lepus, this is a very small red dwarf, considered to be the smallest size that active stars could be.
61 Cygni B
Percentage of solar mass: 63%
Percentage of solar radius: 60%
Lacaille 9352
Percentage of solar mass: 47%
Percentage of solar radius: 47%
First seen in 1881 some 10.7 light years from Earth in the constellation of Piscis Austrinus, it has a high 'proper motion' speed against background stars.
Kapteyn's Star
Percentage of solar mass: 28%
Percentage of solar radius: 29%
12.76 light years away, it may originate from a galaxy absorbed by our own.
Barnard's Star
Percentage of solar mass: 14.4%
Percentage of solar radius: 20%
The fourth-closest star to the Solar System, the British Interplanetary Society used Barnard's Star as the target for the first serious interstellar mission study.
Proxima Centauri
Percentage of solar mass: 12.2%
Percentage of solar radius: 15.4%
Discovered in 1915, Proxima is the closest star to the Solar System at only 4.25 light years away. In August 2016 our nearest exoplanet was found orbiting it.
Van Biesbroeck's Star
Percentage of solar mass: 8.8%
Percentage of solar radius: 12%
A dim red dwarf star 19 light years from Earth, seen in the constellation of Aquila. It's also a variable star known to produce bright flares.

MULTIVE

ARE WE LIVING IN A ERSE?

Reported by Giles Sparrow

Could our entire universe be just one small part of many? The evidence is mounting up...

Have you ever wondered how different your life would be if you had made different decisions? You may never know what may have been, but incredibly, all those 'what if' scenarios may have played out somewhere. Over the past few years, support for the idea that we live in a 'multiverse', in which our universe is just one tiny bubble among countless others, has been gaining strength.

For many people, the term 'multiverse' conjures up pictures of parallel realities, some with just a slight difference from our own. And that sort of multiverse is indeed predicted by the 'many worlds' interpretation of quantum mechanics – the strange but highly successful model of how the universe works on the smallest scales – wherein every possible quantum state branches off into a new universe. In other words, every action that is physically possible, every choice that can take place, can happen and will happen, somewhere.

Such parallel universes might exist, and evidence for this 'many worlds' interpretation of quantum mechanics that invokes them might one day be found, but they would be forever unobservable, separated from our universe in ways we can hardly comprehend. Cosmologists like Matthew Kleban are instead interested in a more concrete form of multiverse – something beyond the realm of our current universe, but which we might nevertheless learn about. "We have a horizon in cosmology that's a lot like the horizon on Earth," explains Kleban, a professor of physics at New York University and a leading multiverse theorist. "If you're on an island in the ocean and climb to the highest point, there's a finite distance you can see, and you don't know what's beyond that horizon by directly seeing it. But you still might be able to get information about it – say a log comes floating up to your island with some plants growing on it. You can learn things from over the horizon because signals of various sorts can reach you from beyond it."

In the case of our universe, the horizon is a lot further away than a horizon on Earth – it's about 46.5 billion light years away from us in every direction. This apparent 'edge' to the universe is caused by the

INFLATION: PROOF FOR A MULTIVERSE?

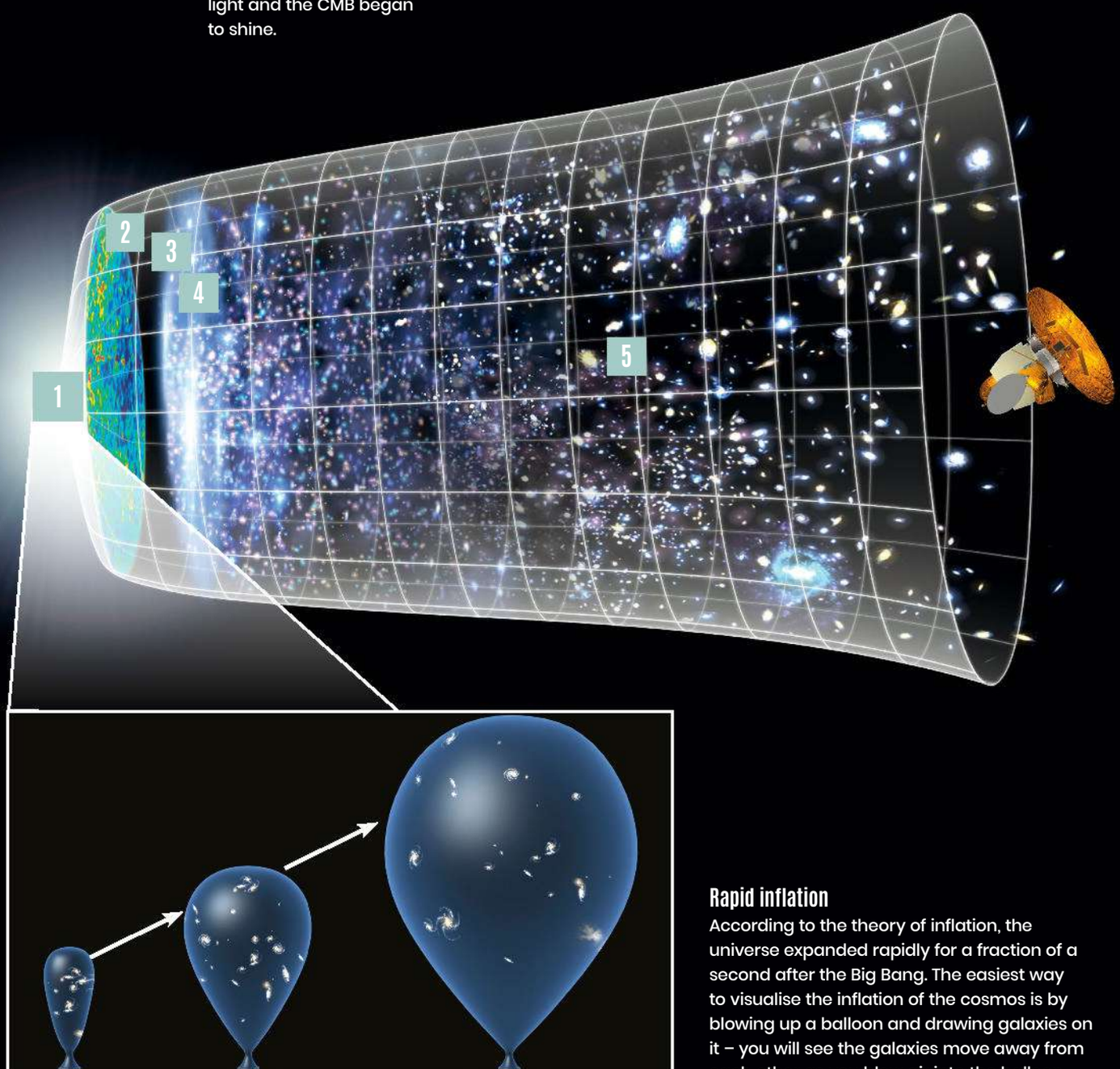
1 Big Bang
In an infinitely dense moment some 13.8 billion years ago, our universe was born from a singularity.

2 Cosmic microwave background
After about 380,000 years, subatomic particles known as electrons cooled enough to combine with protons. The universe became transparent to light and the CMB began to shine.

3 Dark ages
Clouds of dark hydrogen gas cooled before joining together.

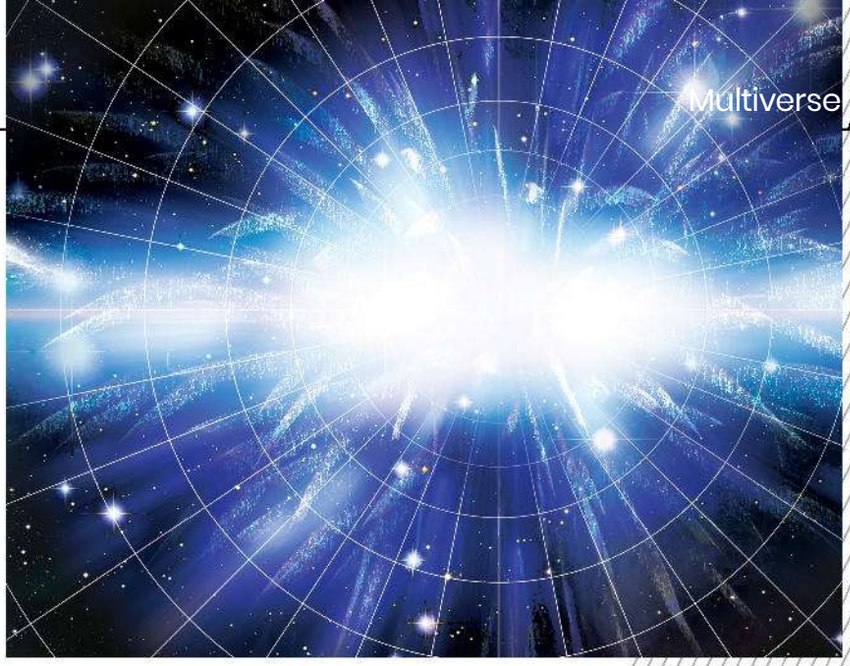
4 First stars
Gas clouds collapsed and fusion in stars began.

5 Galaxy formation
Gravity caused galaxies to form, merge and drift. Dark energy accelerated the expansion of the universe, but at a much slower rate.



Rapid inflation

According to the theory of inflation, the universe expanded rapidly for a fraction of a second after the Big Bang. The easiest way to visualise the inflation of the cosmos is by blowing up a balloon and drawing galaxies on it – you will see the galaxies move away from each other as you blow air into the balloon.


Multiverse

limited speed of light and the fact that the universe is expanding rapidly from the Big Bang – the hot, dense state in which it originated. According to the best current measurements, the Big Bang happened 13.8 billion years ago, and so we can only ever see objects whose light, travelling at 299,792 kilometres (186,282 miles) per second, has had time to reach us. Because the very early universe was so dense, it formed a brilliant opaque fireball that only became transparent after about 400,000 years. Light from that fireball – transformed into invisible microwave radiation in its long journey across expanding space – is the most distant thing we can directly observe. This cosmic microwave background (CMB) radiation has a key role to play in the search for evidence of a multiverse. Its true distance is estimated at 46.5 billion light years because, although the most distant light has been travelling for 13.8 billion years, the space it has been moving through has been expanding during that time.

"We don't know what's beyond the horizon," continues Kleban, "but what we can do is extrapolate from what we can see. On those large scales, the universe is pretty much homogeneous and isotropic, meaning it's pretty much the same in all directions, and as far as we can tell the same in every place. There's definitely a wider universe that's much bigger than what we can see, but it may not be very interesting. That's a basic assumption of modern cosmology that we call the cosmological principle."

Quite how far these distant reaches of space-time stretch is an intriguing question, and one that depends on the shape of space itself. Estimates range from about 250 times the size of the observable universe for a 'closed' and finite universe in which space curves inwards like a sphere, to infinite if space is flat or 'open', curving outwards like a saddle. However far space stretches, though, we'd expect parts of this wider universe to be essentially similar to our own. If the universe really is infinite, or close to it, we'd expect there to be parts of the universe, far away from us, that are exactly like our own observable universe.

How far away would these replica 'universes' – and the replicas of ourselves that would live in them – be? Our observable universe, with its radius of 46.5 billion light years, has enough room for 10^{118} particles. Try to imagine all the different ways these particles can be arranged – mathematics tells us that there are two to the 10^{118} different arrangements of all these particles and that we would have to cross ten to the 10^{118} metres – that's ten to the power of ten with 118 zeroes after it – before we encountered another duplicate universe with duplicate versions of us and our friends, living out parallel existences. That's a long way. In comparison, our observable universe is just 8.8×10^{26} metres across, but if the universe is infinitely big then there's enough room for the particular arrangement of particles making up our universe to be repeated again and again.

What if there's another type of multiverse – one in which universes pop into existence like bubbles and have the potential to be radically different from our own? That's the intriguing possibility that fascinates Kleban and many of his colleagues, and at its heart lies a concept called eternal inflation. "In everyday life we're familiar with the phases of matter – if you think about a water molecule, for example, that can be liquid water, ice or steam. But in fundamental physics it's not just substances that have phases, but everything around us, space and time themselves. Theories like string theory predict a large number of phases, differing a lot more than ice differs from water. They would have different laws of physics. For instance, the fundamental particles of the cosmos, such as electrons and quarks, might

"There's definitely a wider universe that's much bigger than what we can see" Matthew Kleban

A There is growing evidence that we live in a multiverse, with multiple Big Bangs bringing other universes into existence

C A professor of physics at New York University, Matthew Kleban believes that it's highly likely we live within a multiverse

The Planck telescope being prepared for tests at the European Space Research and Technology Centre (ESTEC) in the Netherlands

not exist in some other phase. They might have some different form, or different properties like electrical charge and mass. These phases are kind of a generic feature of most modern cosmological theories."

Among the various properties that could change from one phase to another is the strength of the 'vacuum energy' that permeates empty space. In the past couple of decades, astronomers have discovered strong evidence that a small amount of this energy in our universe – better known as 'dark energy' – drives the expansion of the cosmos to accelerate when it should be slowing down, but in other phases it might be nonexistent, much stronger or even have a negative value. This, it turns out, is key to creating new universes in this kind of multiverse. If all these different phases can exist, there should be transitions between them, just as there are between ice, water and steam.

> **"If the universe is infinite, we'd expect there to be parts of it that are exactly like our own observable universe"**

"You could have a universe that at some initial time has a single phase everywhere," Kleban explains, "but bubbles of different phases will inevitably appear more or less at random, like bubbles appearing in champagne. It's sort of a coin flip whether a given phase would have positive or negative vacuum energy, but at least some of them will be positive. If the vacuum energy is large, then the bubble expands exponentially, doubling in a fraction of a second, doubling again after that and so on. The volume will just explode in those regions. And if those phases are themselves unstable, then bubbles will appear inside them – that's what we call eternal inflation." It's a fairly mind-blowing concept, as Kleban admits: "If all this is correct, we may be inside one of these bubbles, and outside of it is something

THE DIFFERENT TYPES OF MULTIVERSE

From unseen regions of space-time to complex structures, there are four distinct levels

LEVEL 1

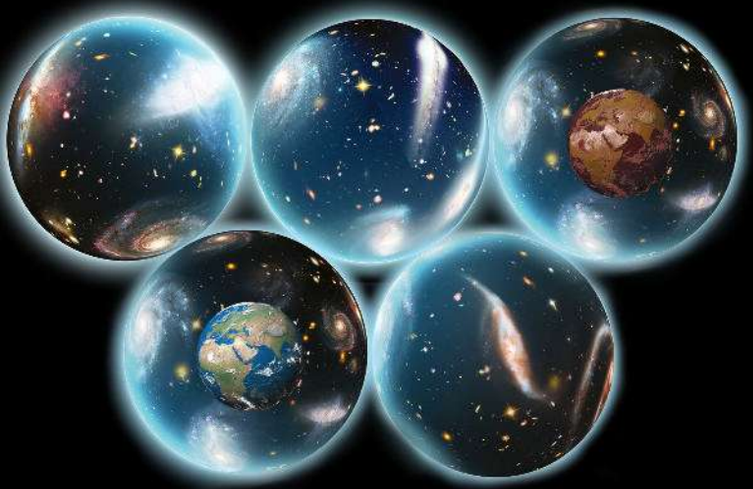
Where an identical Earth exists

The simplest multiverse is one that most certainly exists – the Big Bang model of cosmic origins predicts that every point in the universe has a 'Hubble volume' around it, limited by the expansion of the universe and the distance light has been able to travel in the 13.8 billion years since the infant universe became transparent. In practice, this means our Hubble volume is a sphere 93 billion light years across, but there are many more Hubble volumes extending far beyond what we can see. If the universe has a closed geometry, the number is limited as space curves back around on itself, but if the universe is open, as seems most likely, there may be an infinite number of Hubble volumes, each containing a universe, meaning that somewhere out there, other planets virtually identical to Earth exist.

LEVEL 2

The expanding universe we can't reach

String theory, a potential grand unified theory that aims to explain the fundamental laws of particle physics, suggests that space-time has at least ten dimensions, of which we experience just four – three dimensions of space, plus time – in our universe. The others are tightly curled around each other so we don't perceive them. But our arrangement of dimensions, or phase, is just one among many possible phases – given the right conditions, new ones can pop into existence within a pre-existing phase and then expand rapidly at the speed of light, meaning that they are completely unreachable. This theory of eternal inflation gives rise to a potentially infinite number of bubble universes with different dimensions and laws of physics.



LEVEL 3

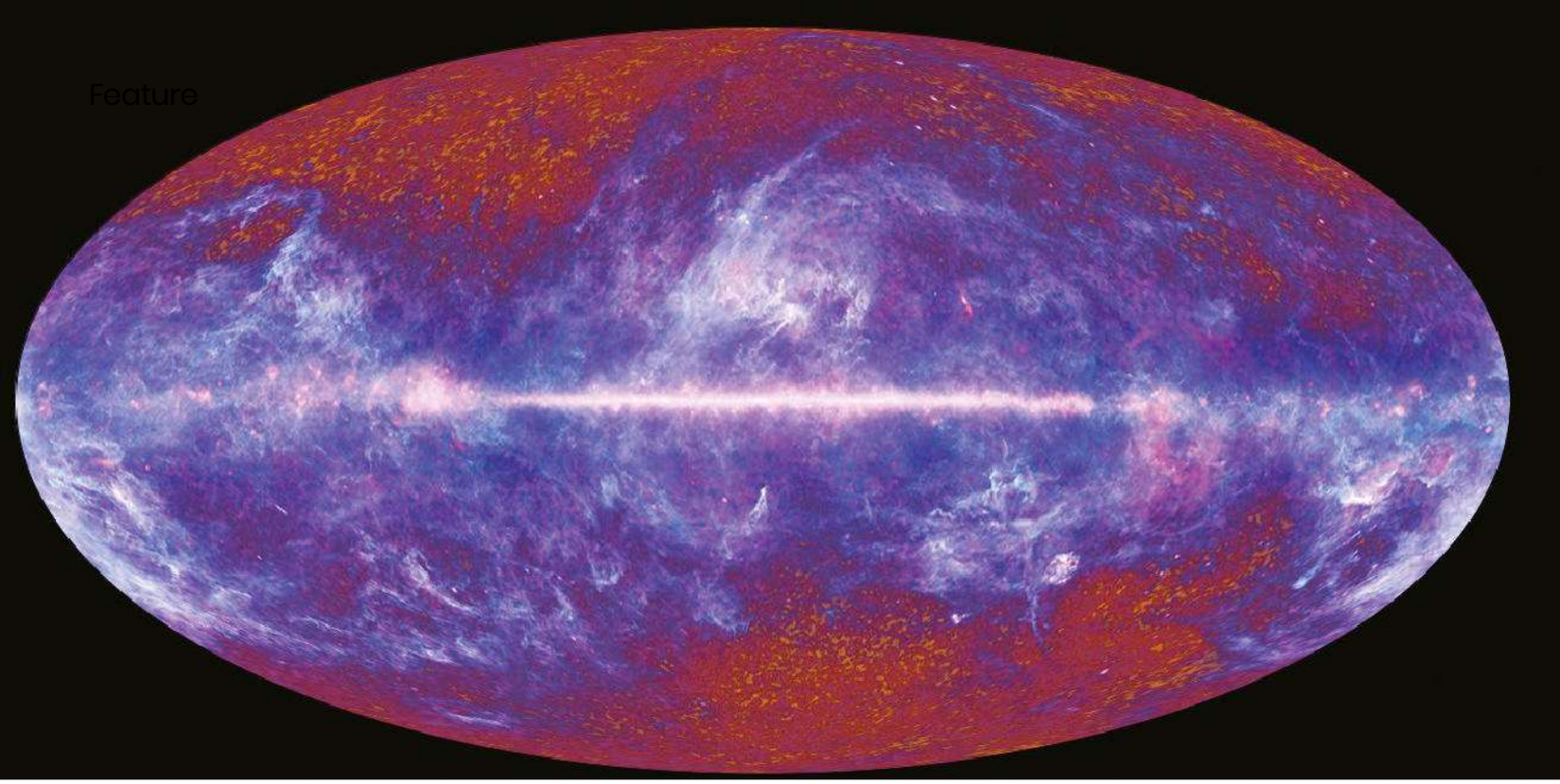
Where your future self exists

According to the many-worlds interpretation of quantum mechanics, every decision point between outcomes – even on the tiniest microscopic scale – sees the universe branch into two mutually unobservable realities. This would involve the creation of multiple universes not in the space described by string theory, but in an infinite-dimensional geometric structure called a Hilbert space. Although you might imagine the many-worlds interpretation giving rise to a more varied multiverse than an extended or bubble model, the reality is that since all three are infinite, the same variety will play out. Some physicists have even argued that if quantum mechanics works in a certain way, then the many-worlds version of the multiverse could be formally equivalent to the more mundane 'single-geometry' versions.

LEVEL 4

The strangest universe of all

As if the ideas of a multiverse as an extension to our own universe, a series of interconnected bubbles or a branching structure of infinite dimensions weren't strange enough, cosmologist Max Tegmark of the Massachusetts Institute of Technology argues that all of these 'lower level' multiverses are simply limited examples of an overarching mathematical multiverse called the 'ultimate ensemble'. This encompasses all possible multiverses that can be abstracted from the messy details of terminology into a purely mathematical description, and therefore includes all the lower level multiverses, plus any other types that still remain to be discovered. This, however, is merely part of Tegmark's semi-philosophical argument that the entire multiverse is a mathematical structure within which conscious entities perceive a physically 'real' world.



> "There are some anomalies in the CMB that look a little bit like bubble collisions"
>
> **Matthew Kleban**

that's probably extremely exotic, most likely very rapidly inflating and has different laws of physics – perhaps even different numbers of dimensions. Once you go beyond the wall of our bubble, the multiverse isn't at all boring and isotropic after all."

Eternal inflation would explain one of the biggest mysteries about our cosmos. The properties of the universe seem suspiciously fine-tuned for life. If the gravitational constant were a little stronger, the charge of an electron a little smaller or the force that binds particles together weaker, then stars and planets would not be able to form and we would not be here. Everything is 'just right', like Goldilocks' porridge, and so far no one has been able to explain why. However, if there are an infinite number of bubble universes, all with slightly different properties, then there's bound to be a universe – our own – where the properties are just right, which would explain why we can exist.

One of the big questions is whether we could ever hope to find evidence that would prove the theory – or at worst prove that this cannot be the case. The idea that the multiverse theory cannot be proved or disproved has been a common criticism from sceptics, and it's an area where Kleban has been concentrating much of his work and research. "What's nice about the theory is there are observational consequences – if other bubbles form close enough to us, then they'll collide with our own bubble. Detecting the consequences with our current technology is a long shot, but it's not impossible, and you can actually work out what you would see, and therefore know what to look for," explains Kleban. "The theory makes testable predictions, and it also makes falsifiable predictions. It predicts that our bubble would need to have an open spatial geometry – if we measure the geometry of our universe and it turns out to be closed, then that would falsify the whole thing."

So what traces would a collision with another bubble make on our universe? As you might expect, a collision between two universes is a highly energetic event. "The walls of these bubbles are extremely rigid, and moving at speeds very close to the speed of light because there's a force that drives their expansion," enthuses Kleban. "The bubble naturally wants to expand and 'eat up' the vacuum energy around it. That gets converted into the kinetic energy of the wall, so these things accelerate, going faster and faster, until they collide. The result is a wave of energy injected into our own bubble, and this propagates across our universe in what we call a 'cosmic wake'. All sorts of things are affected, but the most important is the cosmic microwave background radiation. That's what we want to look at, because it's the oldest and most distant radiation, so it's had the most time to be affected by this sort of event."

Working out what we would see if a multiverse exists will help us know what to look for

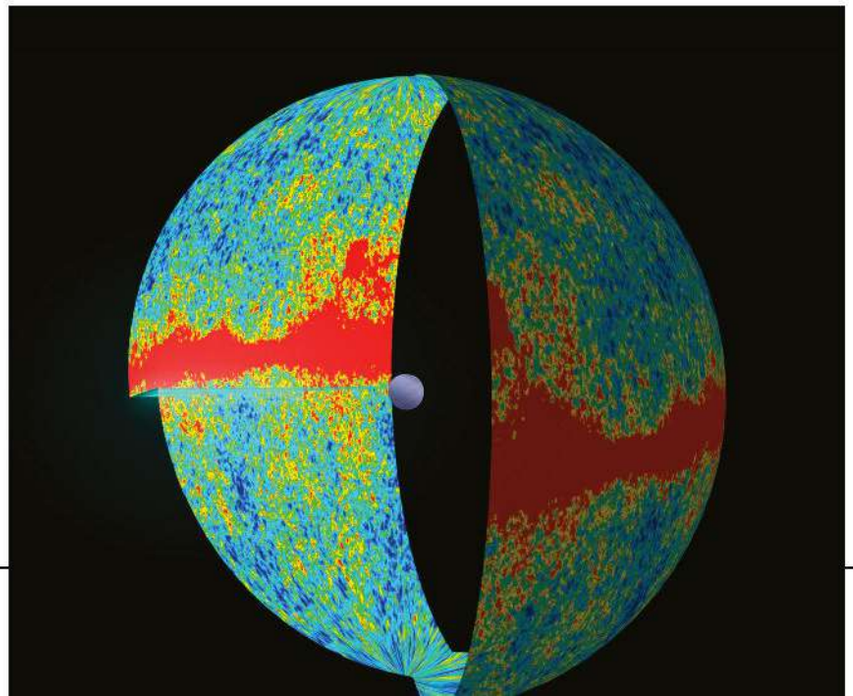
Data from the European Space Agency's defunct Planck satellite is being used in an attempt to prove multiverse theory

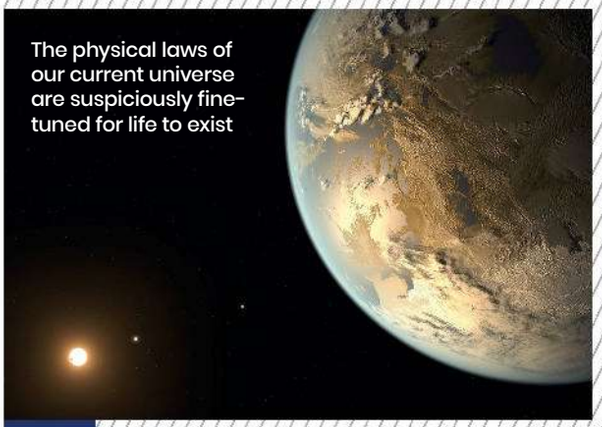
Planck scanned the sky to make the most accurate map ever of the CMB

According to most simulations, a collision between universes would show up as a ring of slightly higher temperature amid the otherwise random variation of the CMB, and also as a polarisation pattern within the radiation – instead of microwaves vibrating in random planes, their oscillations would be aligned in specific directions. "So far we haven't found any strong evidence for such collisions, but there are some anomalies in the CMB that look a little bit like bubble collisions. I don't take them very seriously, but imagine there really was something there on the verge of detectability. It would produce an anomaly of marginal significance. We're waiting on a major new piece of data in the form of an all-sky polarisation map from Planck. That's a partially independent piece of data from the temperature maps, and certain types of bubble collisions would have a very distinct signature in the polarisation."

If our universe does turn out to be just one among infinitely many in a multiverse, the implications for cosmology would be huge. No longer would we imagine space and time as being created in a single event 13.8 billion years ago – that would simply mark the point when our particular phase popped into existence and began to expand. But as Kleban is keen to point out, the study of our potential multiverse is still very much in its infancy. "We focus on certain types of collisions because it seems like those would be the ones we'd have the best chance of observing, but there could be something that we have missed. And the other possibility is an entirely different type of observation that we can't yet do, or haven't thought of. The important thing is that it is possible to detect the multiverse, and once something's possible, we may discover a clever way to do it. We're really still at the beginning."

Giles Sparrow
Space science writer
The author of over 20 books on popular science, Giles holds a degree in astronomy and is an editor specialising in science and technology.





The physical laws of our current universe are suspiciously fine-tuned for life to exist

LIFE IN THE MULTIVERSE

Confirmation of a multiverse could raise some intriguing questions about the origins of life and our own place in the cosmos. According to our current understanding, the physical laws of our universe are suspiciously fine-tuned for life to arise – a tiny difference in any one of several physical constants might make liquid water much rarer, render complex organic chemistry unworkable or leave matter itself unable to hold together. The usual scientific solution to this problem, called the 'weak anthropic principle', simply states that if the laws of the universe didn't have the particular behaviours we observe, we wouldn't be around to see them, so we shouldn't be so surprised. 'Strong anthropic principles' take things a step further with the assumption that, for some reason, the universe has to give rise to something like its present set of life-friendly parameters, perhaps even because the existence of conscious observers is a requirement for the universe to exist.

If this universe is just one within an infinite multiverse, this could significantly change the terms of the debate. The odds of a universe arising with our own parameters would rise from highly improbable to a locked-in certainty, but at the same time so would the odds of any other combination of parameters. So could life exist in these other universes? According to some researchers, it may be far more robust than previously realised. Using computer simulations to study the evolution of universes with various fundamental constants, they have found that stable forms of matter and carbon chemistry can arise in a surprising variety of situations.

@ Tobias Roetsch; NASA; WMAP Science Team; ESA; SPL

FOCUS ON

A MEGATSUNAMI SWEPT OVER MARS AFTER A MASSIVE ASTEROID HIT THE RED PLANET

The impact left a huge crater behind

Reported by Charles Q. Choi

A Martian megatsunami – a giant killer wave that may have reached more than 80 stories tall – may have raced across the Red Planet after a cosmic impact similar to the one that likely ended Earth's age of dinosaurs. Although the surface of Mars is now cold and dry, a great deal of evidence suggests that an ocean's worth of water covered the Red Planet billions of years ago. Previous research found signs that two meteor strikes might have triggered a pair of megatsunamis about 3.4 billion years ago. The older tsunami inundated about 800,000 square kilometres (309,000 square miles), while the more recent one drowned a region of about 1 million square kilometres (386,000 square miles).

A 2019 study found what may have been ground zero for the younger megatsunami – Lomonosov crater, a 120-kilometre (75-mile) wide hole in the ground in the icy plains of the Martian arctic. Its large size suggests that the cosmic impact that dug the hole itself was big, similar in scale to the one from a ten-kilometre (six-mile) wide asteroid that struck near what is now the town of Chicxulub in Mexico 66 million years ago, triggering a mass extinction that killed off 75 per cent of Earth's species, including all dinosaurs except birds. A new study has found what may be the origin point of the older megatsunami – 111-kilometre (69-mile) wide Pohl crater, which the International Astronomical Union named after science-fiction grandmaster Frederik Pohl in August.

The scientists focused on the landing site of NASA's Viking 1, the first spacecraft to operate successfully on the Martian surface. Viking 1 touched down in 1976 in Chryse Planitia, a smooth circular plain in the northern equatorial region of Mars. The probe landed near the endpoint of a giant channel, Maja Valles, carved out by an ancient catastrophic flood, the first time scientists identified an extraterrestrial landscape carved by a river. Unexpectedly, instead of discovering the kind of flood-related features scientists had expected of the site, such as streamlined islands worn smooth by flowing water, they found a boulder-strewn plain.

Now the researchers suggest these boulders may be debris from a megatsunami, the giant wave carrying pulverised rock away from the site of the cosmic impact. "The marine floor would have been tossed up in the air, feeding the wave with sediments and probably aiding the development of a catastrophic debris flow front," said lead scientist Alexis Rodriguez, a planetary scientist at the Planetary Science Institute in Arizona.

The scientists analysed maps of the Martian surface created by combining images from previous missions to the planet. This helped them identify Pohl, which is located about 900 kilometres (560 miles) from Viking 1's landing site within a region of the Martian northern lowlands. "The northern plains of Mars comprise an enormous basin where, about 3.4 billion years ago, an ocean formed and subsequently froze," Rodriguez said. "The ocean is considered to have formed due to catastrophic floods released from aquifers, so my initial approach to looking for a megatsunami-triggering impact was to look for a crater beneath the ocean's frozen residue and above the channels that discharged the ocean-forming floods." Pohl was the only crater the scientists found that met this criterion, he noted.

The researchers simulated cosmic impacts on this region to see what type of impact might have created Pohl. Their findings suggest that Viking 1's landing

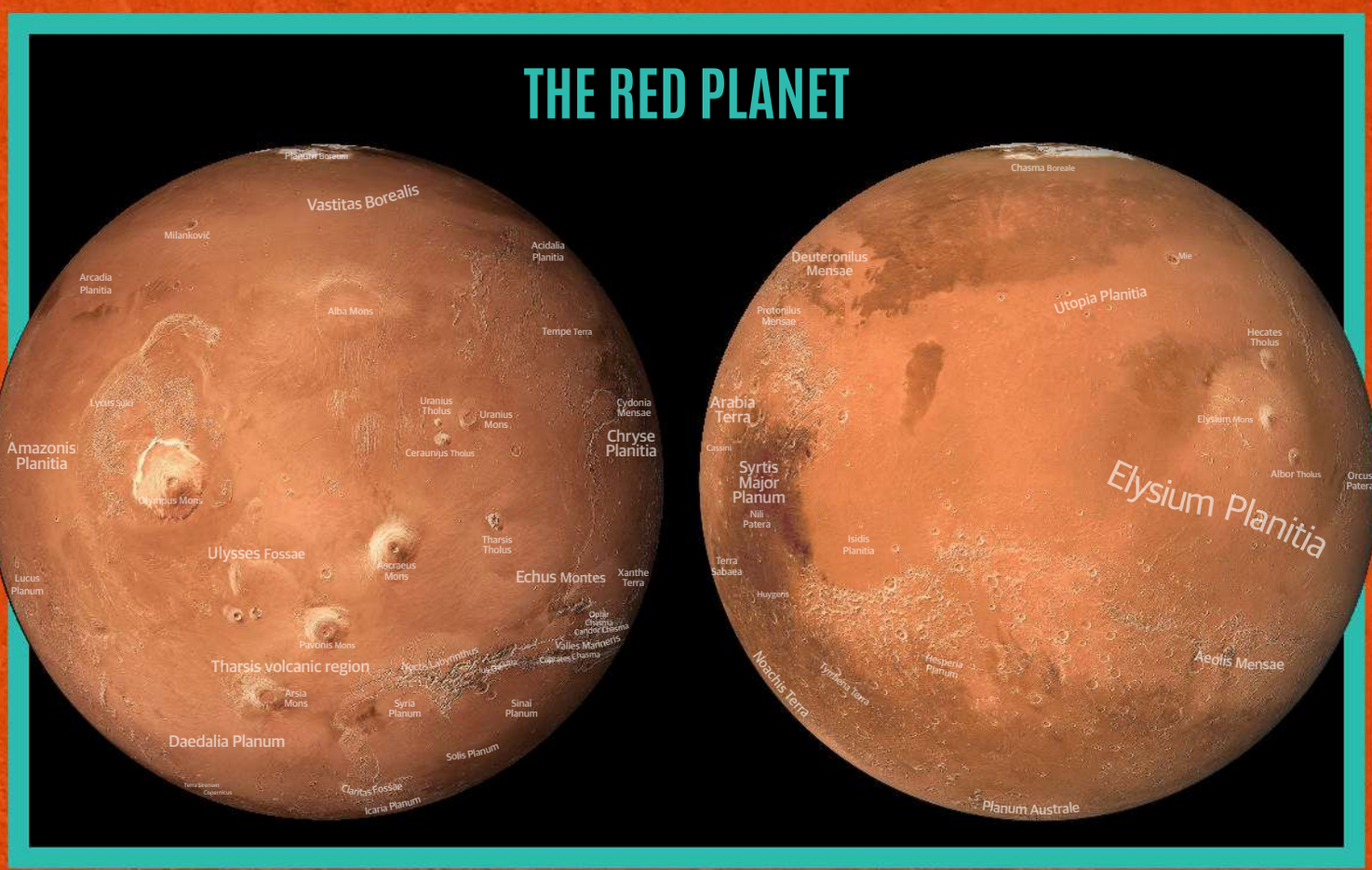
> **"The northern plains comprise an enormous basin where an ocean formed and froze"**
>
> **Alexis Rodriguez**

site is "part of a megatsunami deposit emplaced about 3.4 billion years ago," Rodriguez said. Then the scientists used simulations to understand how a crater with similar dimensions to Pohl might have originated. If an asteroid encountered strong ground resistance, it would have needed to be about 5.6 miles (nine kilometres) wide, with the impact unleashing energy equivalent to 13 million megatonnes of TNT; if the asteroid met weak ground resistance, it might have been only three kilometres (1.8 miles) across, releasing the energy of 500,000 megatonnes of TNT. In comparison, the most powerful nuclear bomb ever tested, Russia's Tsar Bomba, had the strength of 57 megatonnes of TNT.

Both simulated impacts generated a megatsunami that reached as far as 1,500 kilometres (930 miles) from the impact site – more than enough to reach Viking 1's landing site. The massive wave might have initially stretched about 500 metres (1,640 feet) high and measured about 250 metres (820 feet) tall on land. Those statistics would make the Pohl impact similar to that of Chicxulub. Prior work has suggested that impact struck about 200 metres (650 feet) below sea level, formed a crater about 100 kilometres (62 miles) wide and triggered a tsunami about 200 metres (650 feet) high on land.

A view from NASA's Mars Reconnaissance Orbiter of a crater on Mars that formed in 2012

The researchers want to further investigate how the ancient Martian ocean might have changed between the two megatsunamis to see what potential biological effects that change may have had. "Right after its formation, the crater would have generated submarine hydrothermal systems lasting tens of thousands of years, providing energy and nutrient-rich environments," Rodriguez said.



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STAR PROFILE

ETA CARINAE

This star has refused to die thus far, but astronomers are sure it's going to blow up soon

There was a time, about 180 years ago, when Eta Carinae became the second-brightest star in the southern sky. Observed around 1843 in the constellation of Carina (the Keel), the supermassive star experienced an enormous celestial outburst, the cause of which has long since been a mystery. Occurring between 1837 and 1858, the event became known as the 'Great Eruption', causing the star to become ever brighter until it eventually faded to the point it could no longer be seen by the naked eye. Intriguingly, it released as much visible light as a supernova explosion, but unlike novae and supernovae, the brightness remained for some time. The star also didn't die.

Over the years we've come to learn more about Eta Carinae, the star once known as Eta Argus. Having brought us tantalisingly close to a naked-eye witnessing of a supernova within the Milky Way for the first time since 1604, we know that it's a stellar system containing at least two stars. We also know that it's some 7,500 light years away from the Sun and that it's surrounded by a cloud of dust and gas called the Homunculus Nebula, which was ejected from the star following the outburst in 1843. Astronomers believe it's likely to be the next star in our galaxy to explode as a supernova because it's thought to be approaching the end of its life. If it does, it promises to be some sight.

So when was it originally discovered? There's a bit of a riddle around that too. In 1595 a Dutch navigator called Pieter Keyser made some reasonably accurate observations of the southern stars, and these included a fourth-magnitude star that appeared to match Eta Carinae. The earliest firm recording, however, was made by English astronomer Edmond Halley in 1677, who catalogued the star two years later. Years later in the 1830s, English astronomer and polymath John Herschel noted a constant shining at a magnitude of +1.4 at its peak. It wasn't until 2005 that NASA's Far Ultraviolet Spectroscopic Explorer satellite detected the companion star for the first time. This followed a sudden doubling of brightness in 1998 and 1999, which once again allowed the star to be seen with the naked eye.

Now known to be a binary system, there's Eta Carinae A – a luminous blue variable because of its unpredictability – and Eta Carinae B, a massive, luminous, hot star, and both are estimated to be about 3 million years old. Their eccentric orbits bring them close every 5.54 years. Astronomers know this because there's a repeating pattern of changes in visible, X-ray, radio and infrared light. It's at the 5.54-year interval that the X-rays vanish for three months – the time when Eta Carinae A eclipses a region at which X-rays are generated when the powerful stellar winds produced by both stars collide.

But even that's not the full story. In 1887 Eta Carinae erupted again, peaking at magnitude +6.2 five years later, yet still it survives. For how much longer is anyone's guess, although it ensures that astronomers will continue to monitor and study this star closely for many more years to come.

The Carina Nebula can be seen as the brightest star to the left of the image

“Astronomers believe it’s likely to be the next star in our galaxy to explode”

Atmospheric composition

60%
Hydrogen

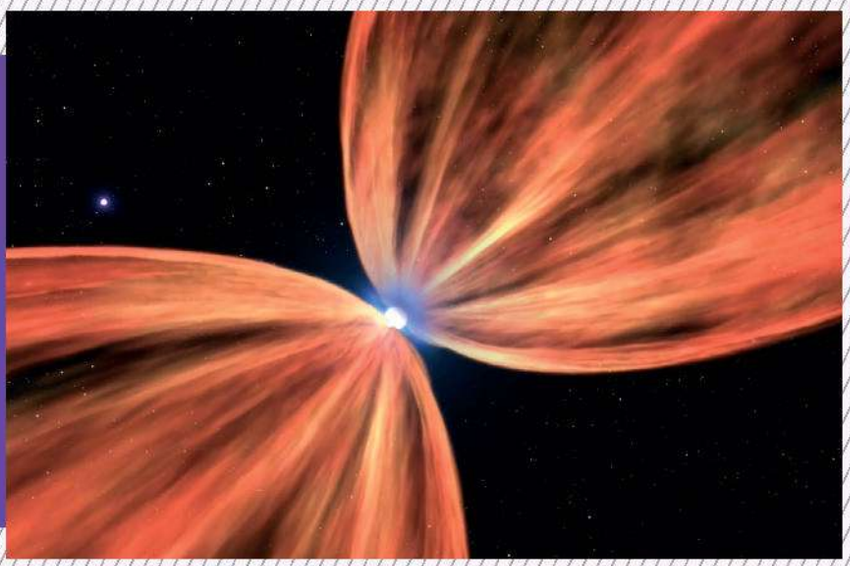
40%
Helium

© NASA/ESA

NEWS FROM ETA CARINAE

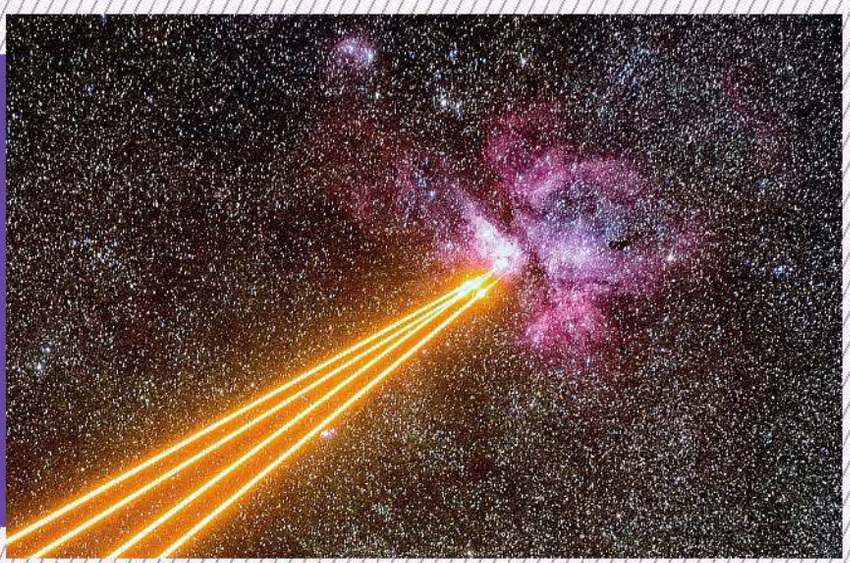
Why didn't the star die?

In 2018, two studies looked at the light that rebounded off interstellar dust as it made its way to Earth. This is called a light echo, and the delay when compared to the light taking a direct route allows experiments to be conducted many decades later. Astronomers at the University of Arizona's Steward Observatory and Armin Rest of the Space Telescope Science Institute in Baltimore, Maryland, both found that the eruption in the 1840s may have been due to a three-way fight. Papers suggest that there were three stars, and that Eta Carinae gobbled one of them up when the system became unstable, sending more than ten times the mass of our Sun into space.



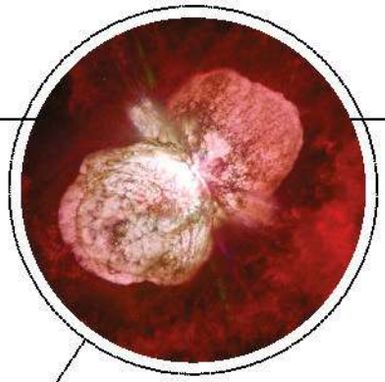
Blasting it with lasers

Since our planet's gassy atmosphere blurs and distorts the view of celestial objects, this method, which enables corrections to be made on telescopes, ensures it's easier to accurately study and explore such faraway objects. Here, laser beams are being sent into the atmosphere towards the Carina Nebula from the Adaptive Optics Facility installed on the Very Large Telescope in Chile. The nebula is a stellar nursery of gas and dust that surrounds the star system. The glow you can see is caused by the beams exciting sodium particles. The reason the nebula is pink is because the stars are shining through its ionised cloud of dust and gas. The laser technique results in more pin-sharp images being taken.



Uncovering intricate details

In 2019, Eta Carinae was captured by Hubble in a new level of detail. Although Hubble has monitored the star system for more than two decades, astronomers used the Wide Field Camera 3 to map the ultraviolet glow of magnesium embedded in warm gas. They expected the red areas of shocked nitrogen gas to have been interspersed with blue-coloured light from the magnesium. But what they discovered was an abundance of magnesium in the gap between the two giant expanding bubbles and the outer layer. They discovered a large amount of warm gas that was ejected in the Great Eruption but hasn't yet collided with the other material surrounding Eta Carinae.



THE EVOLUTION OF ETA CARINAE

- **Age:** 0 years
  Activity: Eta Carinae formed when clouds of gas and dust scattered in the Milky Way accumulated, then collapsed due to gravity.

- **Age:** 290,000 years
  Activity: At this point Eta Carinae was a protostar, having accreted more mass over time. There's a theory that all stars are born with a twin, or even a third sibling.

- **Age:** 3 million years
  Activity: The stars of Eta Carinae fused hydrogen to form helium, and the energy that was released caused them to shine bright.

- **Date:** 1837 to 1843
  Activity: About 180 years ago, the star was observed to erupt with such ferocity that it became the second-brightest star in the sky.

- **Date:** 1887
  Activity: After that Great Eruption, there was a Lesser Eruption, observed in 1887 and reaching sixth magnitude five years on. It also brightened on further occasions.

- **Date:** Today
  Activity: Eta Carinae remains an unstable, volatile star that is likely to explode at some point in a powerful blast called a supernova – but there's still time to observe it.

- **Date:** Future
  Activity: Who knows when it will finally die, but rumours that it will cause a mass extinction on Earth are wide off the mark.

ETA CARINAE BY NUMBERS

100
solar masses. The mass of the primary star compared to 30 for the secondary

Eta Carinae is the only known star to produce a gas cloud that acts like natural ultraviolet laser emissions

6,200,000
MILES PER HOUR
Speed at which the stellar winds of both suns collide

5,000,000
times the brightness of our Sun for Eta Carinae A

35,000
DEGREES CELSIUS
The temperature of the primary star at its highest

1843
The year the Homunculus Nebula came into existence

FUTURE EXPLORATION OF ETA CARINAE

There's not much chance of humans ever sending a spacecraft to Eta Carinae. It's 7,500 light years away, so it'll take a while for anyone to get there even if we somehow crack travel at the speed of light. This means astronomers are going to have to continue to monitor and study the star system from Earth, but that doesn't mean we are settling for second best and that further breakthroughs are unlikely to happen. It's quite the opposite, in fact. There have been many groundbreaking studies in just the past few years, and these have been shedding fresh light on Eta Carinae.

Hubble will be keeping its eye on things for a while yet, while the Nuclear Spectroscopic Telescope Array (NuSTAR) may also be able to give us more clues: in 2018 it found that the star system was accelerating cosmic ray particles to high energies at speeds comparable to light. The James Webb Space Telescope, which launched in December 2021, studies infrared light from celestial objects. It does so with greater clarity and sensitivity than other missions, and there are already plans to direct the spacecraft in the direction of Eta Carinae. The star system's pillars of dust can be clearly seen in infrared light, so more information will surely be ascertained in the years ahead. Astronomers will also benefit from other upcoming telescopes, such as the Giant Magellan Telescope, the Square Kilometre Array and the Extremely Large Telescope. These will prove essential for the studying of star systems and allow for a level of detail that could only be dreamed of not too long ago.

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TEN AMAZING SPACE STATION EXPERIMENTS

The International Space Station is more than just an outpost in space – it's a huge orbiting research laboratory

Interviewed by Laura Mears

The International Space Station (ISS) houses an incredible array of cutting-edge research facilities, allowing scientists back on Earth to conduct pioneering experiments in space. Different space agencies, academic institutions and private companies from across the world share the onboard facilities, taking it in turns to perform their experiments. Delicate tests can be conducted in microgravity inside the station itself, and outside experiments can be exposed to vacuum and radiation. With a clear view of space and out of the reaches of Earth's atmosphere, the ISS is also the perfect place to investigate the universe.

Some experiments investigate the physical sciences, looking at the behaviour of different materials in space, while others focus on biology, helping us understand how the human body is affected by space travel or how to grow food away from Earth. Others monitor Earth, taking advantage of the ISS' incredible view of our planet below.

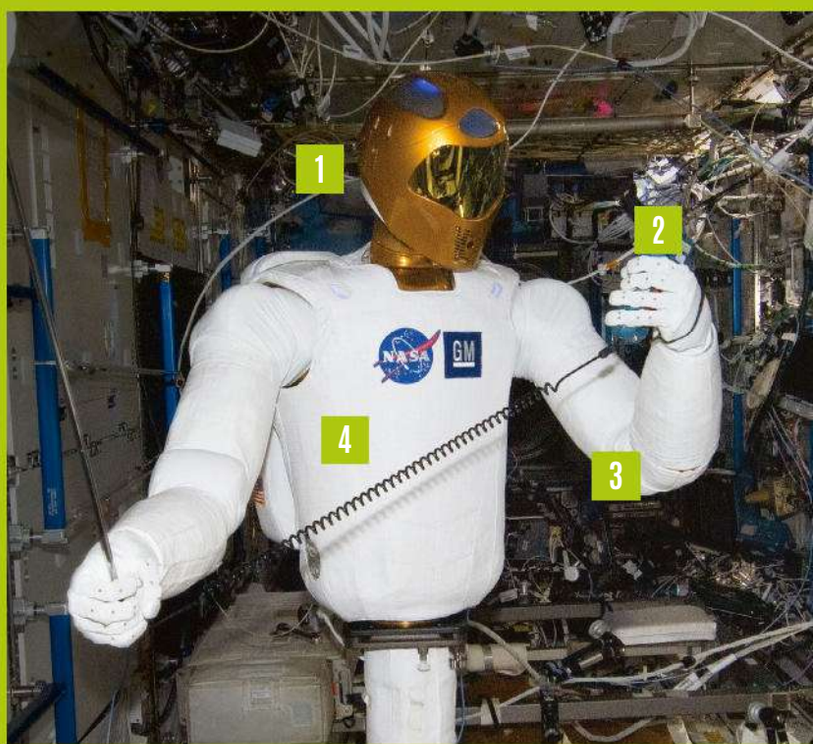
The station also houses sophisticated equipment to examine space itself, and inside, advanced technology can be developed and tested in microgravity. Join us as we investigate ten awesome International Space Station experiments, from robotic crew members to an orbiting coffee machine.

ONE
WORKING WITH A HUMANOID

The ISS is always occupied by at least three human crew members, and since February 2011 they've been joined by Robonaut 2. On its arrival, the robotic crew member met the ISS commander with a handshake and greeted the public by signing 'hello world'. This incredible robot is the result of a collaboration between NASA, General Motors and Oceaneering Space Systems. Together they wanted to create a robot that was capable of carrying out repetitive, uncomfortable or dangerous tasks.

Robonaut 2's hands are flexible like our own – its thumb can bend to touch all of its fingers – and it has a grip strength equivalent to a human hand. Its arms are soft and padded and contain springs that give way easily when pushed, allowing astronauts to work safely alongside Robonaut 2.

The robot has infrared cameras for depth perception and an additional four visible-light cameras that help it 'see' in stereo. Since 2014, it also has a pair of flexible legs, each fitted with an 'end effector' where the foot should be, allowing it to move freely around the station. With a little more upgrading, the team hope that this robotic crewmate will eventually be able to work on the outside of the ISS.



TWO
SQUID BEHAVIOUR IN MICROGRAVITY

The final flight of NASA's Space Shuttle program carried some unusual passengers to the ISS: three Hawaiian bobtail squid. These little sea creatures are usually found hiding in the sand on shallow seabeds, and at only five centimetres (two inches) long, they're the perfect size for experiments.

This species was chosen because of its close relationship with another organism. Hawaiian bobtail squid naturally share their bodies with a species of bacteria called *Vibrio fischeri*. These bioluminescent microbes light the squid's silhouette, helping keep it camouflaged in the dappled light of the water.

The squid only live for around ten months, but these intrepid explorers made the journey into space to help researchers understand how bacteria that live inside animals are affected by microgravity. Beneficial microbes inside the human body help protect us from infection, so these experiments are really important for astronaut health on long-term missions. With only three studied, no firm conclusions could be made from this first experiment, but the team are now confident that the squid and their bacteria can survive the long trip.

The squid housed in tubes of seawater

1 Human-like senses
Robonaut 2 has over 350 sensors, including five cameras in its helmet.

2 Opposable thumbs
Robonaut 2 has flexible hands, and can easily touch its little finger to its thumb.

3 Padded metal
The robot is made from aluminium and steel, but is coated in soft protective padding.

4 Robonaut's brain
The 38 processors responsible for controlling it are housed inside its torso.

THREE

GROWING TOMATOES IN SPACE

Young people across the US and Canada are working with NASA to find ways of growing food in space. Throughout the school year, 1.2 million tomato seeds were sent out to 18,000 schools. Half of these seeds made the journey to space and back, spending five months on board the ISS under the watchful eye of astronaut Scott Kelly.

The students weren't told which were the space seeds and which stayed on Earth, so they treated both the same, planting them, then watching and recording as they germinated and grew, teaching the students about plant life cycles and how to go about conducting rigorous scientific studies.

Each school then submits its data, informing NASA how many seeds they planted, and how many actually grew. The results help scientists understand what happens to seeds when they are taken into space, and will be used to help plan missions to Mars.

During the two-year journey to the Red Planet, the crew would need to grow tomatoes that are not only nutritious, but also have leaves that can produce clean drinking water that can be captured as it evaporates.

1 Preparing the seeds
600,000 seeds were prepared and packed, ready for the journey into space.

2 To the ISS
The seeds went on board the SpaceX Dragon, a privately owned cargo craft.

3 Time in space
The seeds spent five weeks in microgravity.

4 Back to Earth
They were sent to thousands of schools across North America.

5 The experiment
Earth and space seeds were grown in the same conditions.

6 Citizen scientists
Since 2001, more than 3 million students have been involved.

FOUR

HOW SPACE TRAVEL AFFECTS THE HUMAN BODY

The crew on the ISS spend over an hour every day exercising. This is not only vital for their wellbeing, but also helps scientists gather information about the effects of space on the human body.

There are three main pieces of gym equipment on board the space station – an exercise bike, a treadmill and a weights machine, each of which has been modified for the conditions on board the ISS.

A standard weight machine wouldn't work without gravity, so the ISS Advanced Resistive Exercise Device uses pistons and vacuum cylinders instead. The astronaut has to pull against the vacuum to move the machine, and specially designed flywheels help make it feel more like lifting weights on Earth.

The crew keep fit using specially designed equipment

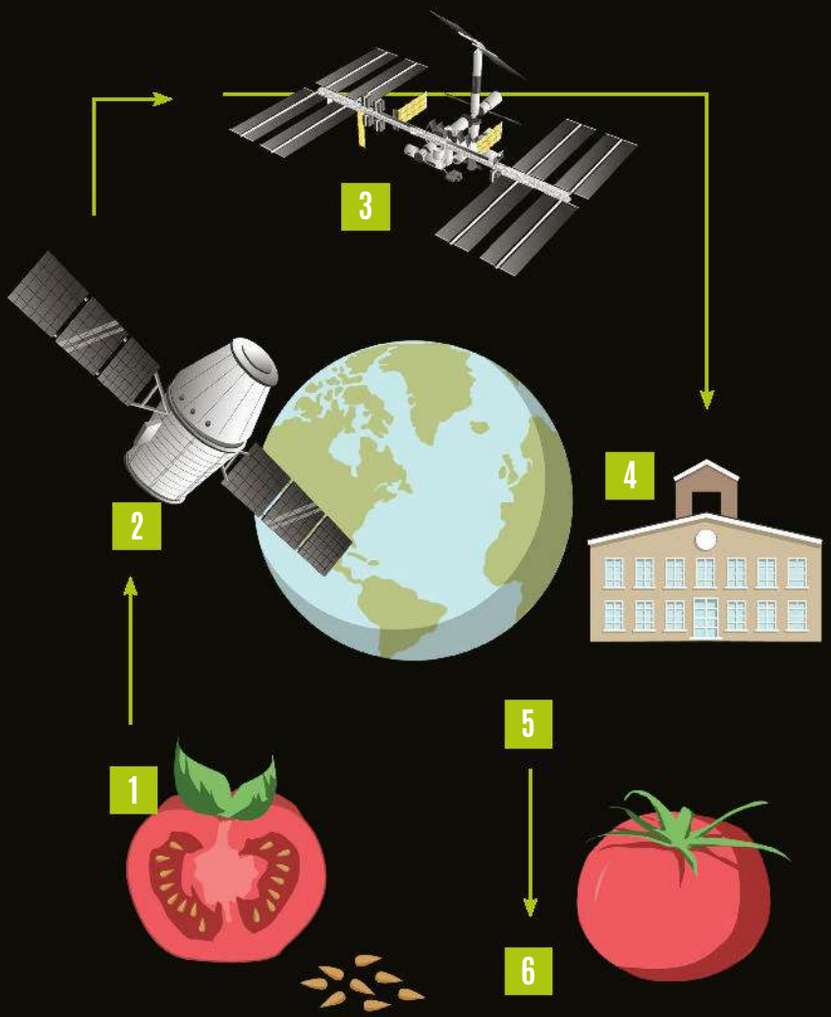
FIVE

3D PRINTING WITHOUT GRAVITY

Imagine what space travel would be like if new parts and tools could be delivered to astronauts at the touch of a button. That is the aim of Made In Space and its 3D printer on board the ISS.

In November 2014, NASA astronaut Barry "Butch" Wilmore became the first person to use a 3D printer in space. After a few test runs, a Made In Space engineer sent the plans for a wrench to the ISS for the first test of on-demand printing. Four hours and 104 layers of plastic later, the wrench was finished.

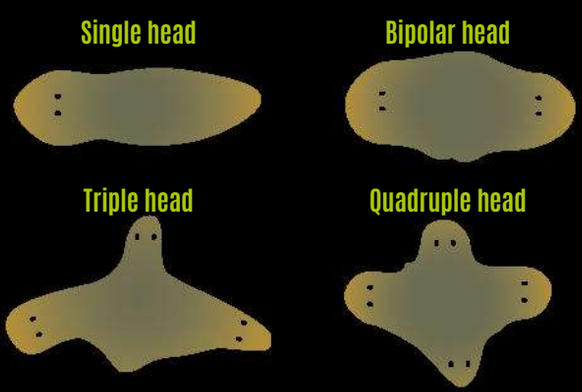
Operating a 3D printer in space is a huge technical challenge. On Earth, gravity helps the plastic to sit in neat layers as it is extruded, but on the ISS the components would float around. Made In Space has tackled this problem with some innovative but top-secret technology.



SIX
STEM CELLS WITH FLATWORMS

Flatworms are some of the simplest life forms on the planet, but they have an incredible ability: if you cut them in half, each piece will grow into a fully formed flatworm. This is down to stem cells positioned throughout their bodies, ready to spring into action if damage occurs by dividing and changing to form the cells needed to build new tissues and organs. Scientists are starting to understand how this process happens on Earth, but wondered if the stem cells would still function without gravity.

Flatworms travelled to the ISS and back in sealed tubes, where they were monitored to see how well they repaired themselves. The flatworms spent five weeks in space in test tubes filled with half air and half water, while another set of the creatures were sealed in the same set up in total darkness. The activation of various genes was also tracked and compared to the patterns that we see back on Earth. The spacefaring flatworms, on their return, were found to be initially paralysed and curled up before unwinding themselves, gravitating towards light, altering their metabolic rate and regrowing two heads if they were unlucky enough to be chopped up.



K10 borrows and advances technology from undersea exploration

Under certain conditions, flatworms can generate multiple heads

SEVEN
CONTROLLING ROVERS FROM THE ISS

In June 2013, flight engineer Chris Cassidy took control of a K10 robot at NASA's Ames Research Center in California, not from the ground, but from the ISS. He drove around a simulated moonscape for three hours, demonstrating the future technology that could allow astronauts in space to send robotic scouts to other worlds.

K10 is a four-wheel-drive robot weighing about 100 kilograms. It borrows technology from undersea exploration and can also intelligently plan its route across the terrain. K10 moves at a slow walking pace and builds a 3D picture of its environment using a combination of cameras and a laser.

K10 is also able to deploy radio antennae, becoming a mobile communications platform. The technology is being tested for a possible NASA Orion spacecraft mission, which aims to take a crew into orbit around Earth behind the far side of the Moon. With technology like this, astronauts could use a remote-controlled robot to deploy a radio telescope onto the Moon's surface.

EIGHT

TESTING INFLATABLE HOMES

Humans will need places to live when we travel to the Moon, Mars and beyond, and where better to test them than the ISS? The Bigelow Expandable Activity Module (BEAM) was carried to the space station in 2016 on board a SpaceX Dragon. Packed up, BEAM only measures 1.7 by 2.4 metres (5.7 by 7.8 feet), but when filled with pressurised air it inflates to form a space 3.7 by 3.3 metres (12 by 10.5 feet), about the size of a small bedroom.

It's made up of many layers, including an air cushion and a shield that will protect the structure from damage by dust and debris. In the case of a collision with a larger object, the inflatable room is designed to leak air slowly, allowing the astronauts on the space station plenty of time to react.

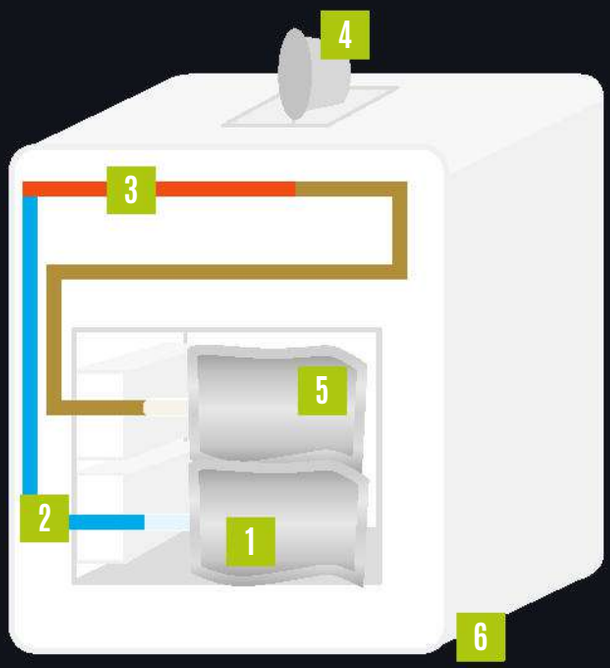
The module was docked with the ISS' Tranquility node, but wasn't ready for use straight away. A number of tests are being carried out on BEAM, which include temperature, pressure and radiation readings being recorded around the clock. Astronauts enter every three months to take measurements and perform an inspection of its condition. All being well, inflatable rooms might become an integral part of our space habitats.

NINE

MAKING COFFEE IN EARTH ORBIT

Making hot drinks in space is a complex business, but not content with the idea of a life without coffee, the Italian Space Agency teamed up with space food engineering company Argotec and coffee giant Lavazza to design a machine that could be used in microgravity. Water at high temperatures and pressures is difficult to manage in space, so the project was a serious engineering challenge. Plastics had to be replaced with steel tubing capable of withstanding pressures of up to 400 bar – 400 times the air pressure at sea level – and the finished product weighs a hefty 25 kilograms.

The ISSpresso machine works in a similar way to coffee machines on Earth, and even uses the same Lavazza coffee capsules. It can also make tea and broth. An astronaut in need of a hot beverage just has to follow these simple instructions: plug the machine into a utility outlet panel and install a water pouch. Then install a NASA standard drink bag and a capsule containing the desired drink. Three minutes later, the drink is ready. Italian astronaut Samantha Cristoforetti was the first to enjoy a coffee in space.



1 Water pouch
The astronaut first fills a pouch with water, then fastens it to the coffee machine.

2 Water in
The water is pressurised, passing through a series of steel tubes into the heater.

3 Heating
Once the water has been pressurised, it's heated to the right temperature.

4 Coffee capsule
Hot water passes through a capsule, and fresh coffee is pushed into the pouch.

5 Pressure difference
A differential means that when the straw goes in, the fresh coffee smell rushes out.

6 Coffee time
The whole process takes three minutes, barely longer than you have to wait for a coffee back on Earth.

There's no need to miss a caffeine fix, even in space

BEAM was carried to the space station in 2016 on board a SpaceX Dragon

TEN

HUNTING FOR DARK MATTER

Something about the universe doesn't quite add up. Everything that we can see – from stars and planets to galaxies and black holes – only represents around five per cent of what is known to be the total mass and energy. Where – and what – is the other 95 per cent?

A total of 56 institutes from 16 countries around the world have come together to find the answer. The Alpha Magnetic Spectrometer (AMS-02) weighs 8,500 kilograms and was delivered to the ISS on the penultimate voyage of the Space Shuttle Endeavour. Since 2011, AMS-02 has been monitoring for signs of antimatter, dark matter and dark energy – the missing pieces of the universe.

Assembled at CERN, the home of particle physics, AMS-02 is a particle detector. At its core is a huge magnet that measures the charge of any particle coming in, and an arsenal of instruments identify other properties, including a 'stopwatch' that times the particles as they pass through.

AMS-02 is searching for cosmic rays, extremely high-energy radiation, some of which may be charged particles released when dark matter collides. So far it has recorded over 100 billion events, and will continue trying to understand the missing portion of the universe.

"Since 2011, AMS-02 has been monitoring for signs of antimatter, dark matter and dark energy"

1 Transition radiation detector
This detector can tell the difference between particles by the X-rays they release.

2 Time-of-flight scintillator
Measures how long each particle takes to pass through the detector.

3 Silicone tracker
Measures the paths of particles as they are bent by the magnet.

4 Permanent magnet
Bends the path of charged particles as they pass.

5 Ring-imaging Cherenkov counter
Identifies the type of charged particle by measuring the radiation it emits.

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FOCUS ON

HUBBLE CAPTURES A DAZZLING EMBRACE OF MERGING GALAXIES

The mutual gravity during the collision is warping the structures' shapes to form a ring

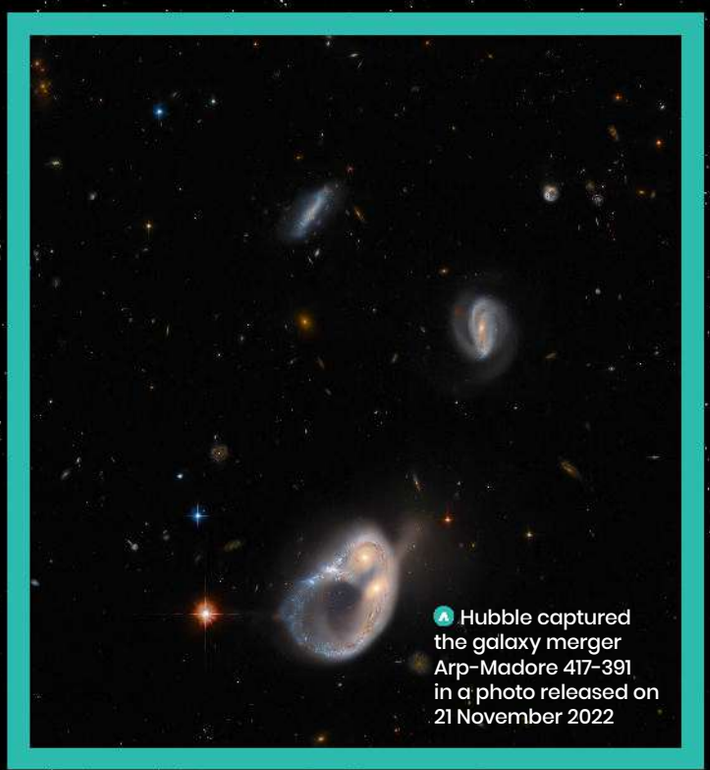
Reported by John Loeffler

Two merging galaxies' immense gravity warps their arms into an embrace in a stunning new image from the Hubble Space Telescope. The galaxy merger, known as Arp-Madore 417-391, was first described in the Arp-Madore catalogue of strange and unusual galaxies and is located about 670 million light years away in the Southern Hemisphere constellation of Eridanus. What makes this particular galaxy merger so compelling is the force of the two galaxies' gravity twisting and distorting their shapes to form an irregular ring, with the nuclei of the two colliding galaxies left side by side on the bottom left of the structure.

Arp-Madore 417-391 is somewhat reminiscent of a different class of galactic structure known as a ring galaxy, the most famous of which is known as Hoag's Object. These ring galaxies make up less than 0.1 per cent of all known galaxies. As the name suggests, ring galaxies have a pronounced ring structure rather than the arms of a typical spiral galaxy. Astronomers are still debating how these kinds of galaxies form, but galaxy collisions are considered a likely candidate.

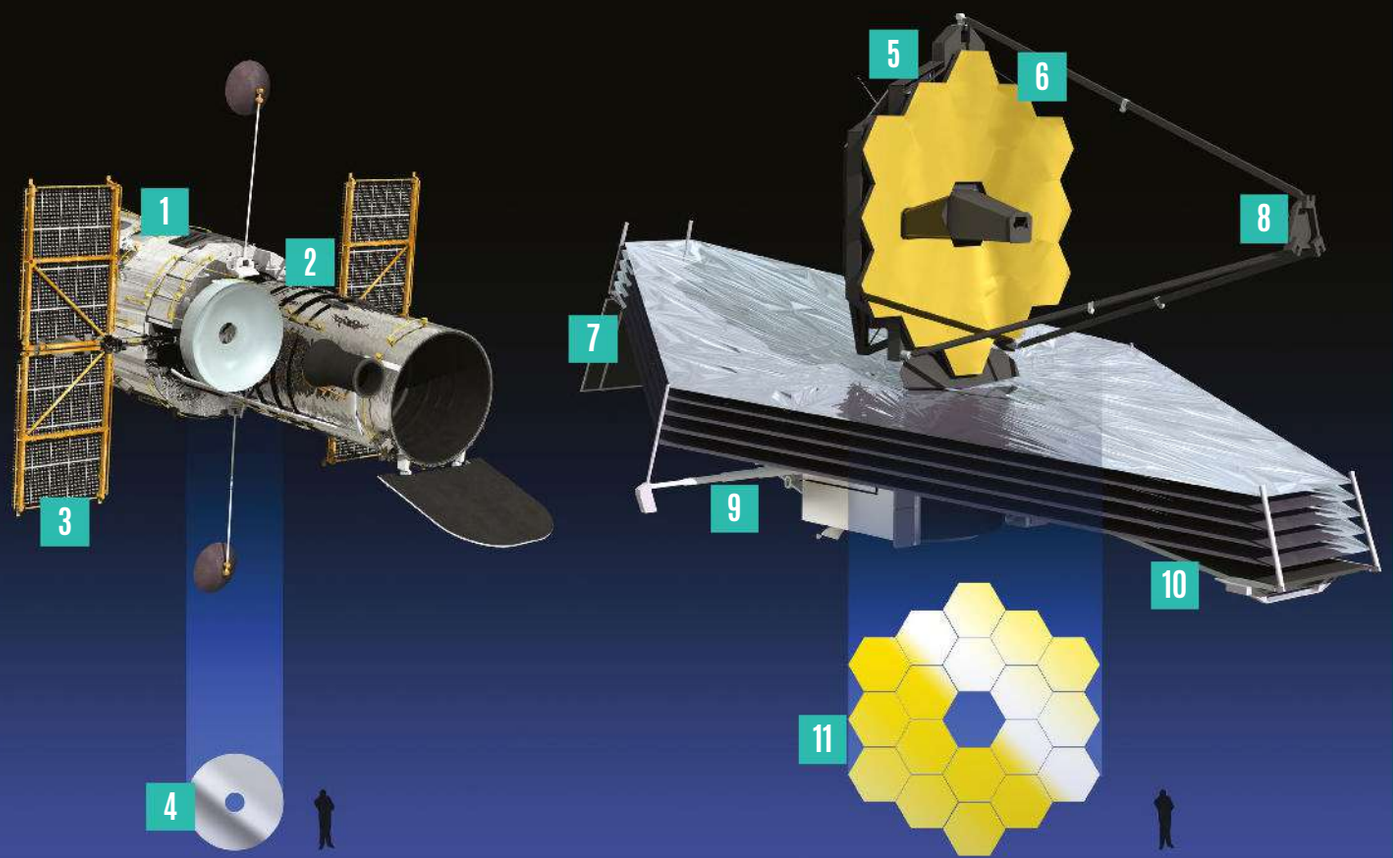
Hubble snapped the image during its survey of 'intriguing targets', meant to identify candidates for more detailed follow-up observations by the James Webb Space Telescope. The Hubble team recently released another such Arp-Madore object, called Wild's Triplet, which also shows the gravitational influence of a pair of interacting galaxies, though it's not as dramatic as Arp-Madore 417-391.

To capture the image of Arp-Madore 417-391, Hubble relied on its Advanced Camera for Surveys, which is specifically tailored to hunt for ancient galaxies and galaxy clusters that formed in the early days of the universe. The James Webb Space Telescope is much better suited for this kind of deep-space observation, however, thanks to its sensors that can see much further into the infrared spectrum, therefore revealing finer details of galaxies that are even older than Arp-Madore 417-391. It's too soon to say whether Webb will make a return to Arp-Madore 417-391, but compiling a list of interesting candidates for the advanced space telescope is a necessary first step.



A Hubble captured the galaxy merger Arp-Madore 417-391 in a photo released on 21 November 2022

HUBBLE VERSUS WEBB



1 Secondary mirror
This mirror brings the light from the primary mirror to a focus in the instruments behind the primary mirror.

2 Packed with instruments
The aft shroud contains Hubble's wide-field camera and many other important instruments.

3 Solar array
Hubble has two panels that absorb sunlight and convert it directly into electricity.

4 Primary mirror
Measuring 2.4 metres (7.8 feet) in diameter, Hubble's mirror is the smoothest of its size.

5 ISIM
Webb's cameras and science instruments are housed in a module behind the primary mirror.

6 Primary mirror
18 hexagonal segments made of beryllium and coated with gold are used to capture faint infrared light.

7 Trim flap
This ensures that the spacecraft is stabilised as it collects images and data.

8 Secondary mirror
This mirror reflects light gathered from the primary mirror into the science instruments.

9 Solar power array
The array is always facing the Sun, allowing sunlight to be converted into electricity to power the observatory.

10 Multilayer sunshield
Five layers shield the observatory from light, radiation and heat from the Sun and Earth.

11 Massive mirror
Each of Webb's hexagonal-shaped mirror segments measures 1.3 metres (4.2 feet) across.

© NASA

MYSTERIES OF THE UNIVERSE

WHY DOESN'T JUPITER HAVE PROMINENT RINGS?

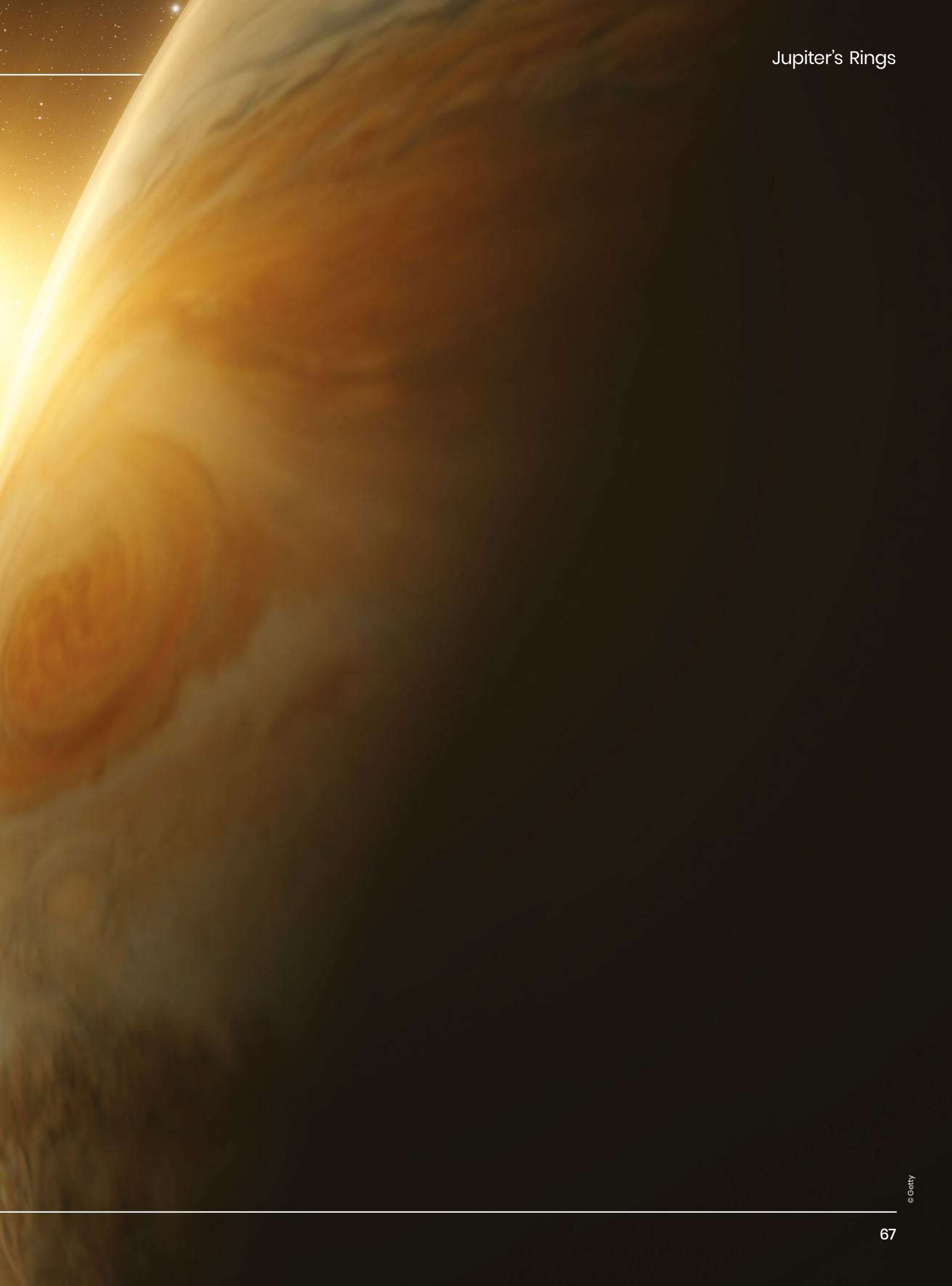
Given how massive Jupiter is, the gas giant should theoretically have a set of thick rings, so why are they so thin?

Reported by David Crookes

Of all the planets in the Solar System, Saturn is perhaps the most visually stunning. Ever since its rings were discovered by Galileo in 1610, this gassy world has been a source of great fascination, with many studies looking at where, when and how those whirls of ice and rock were formed. Yet Saturn isn't the only planet with rings. Jupiter, Uranus and Neptune have them too, but they're not as prominent. In the case of Jupiter, this has proven to be particularly baffling since Jupiter is 15 per cent larger than Saturn and has three times the mass. In that sense, astronomers would expect the gas giant to have rings even more spectacular than its neighbour. Instead they're mere whispers in comparison.

Among those keen to discover why this happens to be the case is planetary astrophysicist Stephen Kane from the University of California, Riverside. He recently took to Twitter to point out the discrepancy, writing: "Jupiter is more massive than all other Solar System planets combined, so why doesn't it have a substantial ring system like Saturn?" This wasn't a throwaway question in the hope that someone reading would provide an answer. Although it has long been a mystery, Kane was actually flagging up a recent study which has gone a long way to shedding light on the situation. "Jupiter's relative lack of rings has long been an issue, but one that few have thought about," Kane tells **All About Space**, pointing out that the planet's rings are so thin they were only discovered when Voyager 1 performed a flyby in 1979. "It's a question that has always bothered me because Jupiter is more massive than all other Solar System planets combined, implying it should have the largest amount of material orbiting it."

To put this situation into even greater context, Kane also informed Twitter that Uranus' ring system was



© Getty

JUPITER'S RINGS BY NUMBERS

THIRD
ring system to be discovered

4
faint rings: a main, an inner and two outer

2,000 TO 12,500
kilometres thick

ZERO
Amount of ice they contain

5%
Amount of incoming sunlight the rings reflect

95%
Amount of incoming sunlight the rings absorb

92,000
kilometres above the planet's cloud tops

225,000
kilometres from Jupiter at their farthest

"Jupiter may have had rings in the past that have since dissipated"
Stephen Kane

discovered in 1789 – just eight years after the planet itself was first observed by astronomer William Herschel. Given that Uranus lies beyond Saturn and is a much smaller planet, it shows how faint Jupiter's nebulous rings really are since they can't be observed using standard astronomical equipment. Something must have happened to Jupiter, but what?

Before beginning their study, Kane and his graduate student Zhexing Li had an idea of how Jupiter could look today: a gas giant surrounded by rings that are more prominent and spectacular than those around Saturn. But they also knew ring structures around the planets of the outer Solar System could be temporary, giving rise to the possibility that Jupiter did have fantastic rings at some point in its evolution, only to have lost them. "Debate remains as to how long rings survive and whether Saturn's rings may be transitional, so Jupiter may have had rings in the past that have since dissipated," Kane explains. "One mechanism for ring formation is impacts from smaller bodies, and Jupiter would have attracted many such impacts in the past. Based on the mass of the planet alone, a past ring system for Jupiter may well have been far more substantial than Saturn's rings. Since Jupiter is also closer than Saturn, that would have been an impressive sight indeed!"

To better understand why Jupiter is in its current state, the astrophysicists ran what is called an N-body simulation – a way of determining the motion of bodies under the influence of gravitational forces. This simulation took into account Jupiter's orbit, as well as the orbits of four of the gas giant's largest moons, Ganymede, Callisto, Io and Europa. "We ran a dynamical simulation that injects small particles into various orbits around Jupiter and investigated what happens to those particles after a million years and 10 million years," Kane says. "We only included the Galilean satellites because they are overwhelmingly the main 'regular' moons of Jupiter, meaning they likely formed with Jupiter. The other moons are 'irregular' satellites that are non-spherical, many of which were likely captured, and don't contribute to the dynamical evolution of the system."

As those small particles were introduced, the scientists watched and waited to see what would happen. They could see that rings would start to form, but that the moons were having a major effect. The gravitational

If Jupiter had bright rings of ice and rock befitting its size and mass, then the giant gas planet would look something like this

THREE POTENTIAL EXPLANATIONS

Scientists have considered why Jupiter's rings aren't as fantastic as Saturn's

They formed differently

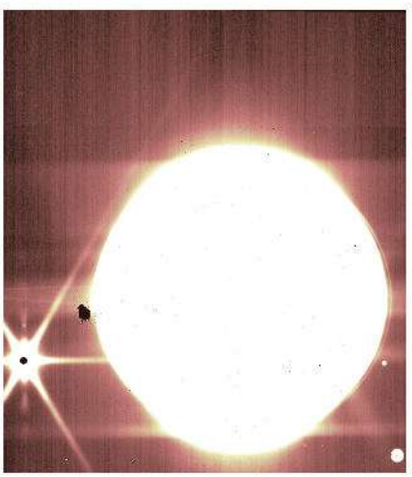
Saturn's rings are made up of large chunks of ice and rock and could have formed from the remnants of a large, icy body. Jupiter's rings are formed by small dust particles. This comes off the smaller inner moons, so are larger particles simply pulled back by gravity?

There's no ice around

Given Jupiter's location in the Solar System, this is unlikely – and that's not even taking into account the planet's icy moons. To that extent, it's possible that Jupiter did once have spectacular rings that included ice, but they've somehow become less prominent.

Jupiter's moons wrecked it

According to the latest theory, Jupiter's moons have prevented ice from settling, and that has destroyed any large rings that might have formed. In this scenario, Jupiter has simply been unable to form amazing rings containing ice at any point in its history.



pull and force of Io, Europa and Ganymede in particular – all within 15 Jupiter radii of the planet – were causing significant dynamical desiccation of material within 3 to 29 Jupiter radii. The moons were destroying the large rings, preventing them from forming properly, and it's an effect that's seen to a lesser degree around Saturn too.

Saturn's icy rings can be affected by its massive orbiting moons, causing ice to be ejected from the planet's orbit. Saturn's rings are also under the influence of the planet's magnetic field, to the extent that NASA believes the entire ring system could be gone within 300 million years. Given the transient nature of planetary rings, it's feasible that Jupiter once had spectacular rings that have since been lost. But that seems not to be the case. "Our simulation showed that much of the ring material is removed from the system after a million years, and almost all of the material removed after 10 million years," says Kane, indicating that the rings were being destroyed before they had a chance to form anything substantial. "It surprised me that the Galilean moons are so efficient at removing ring material from around Jupiter."

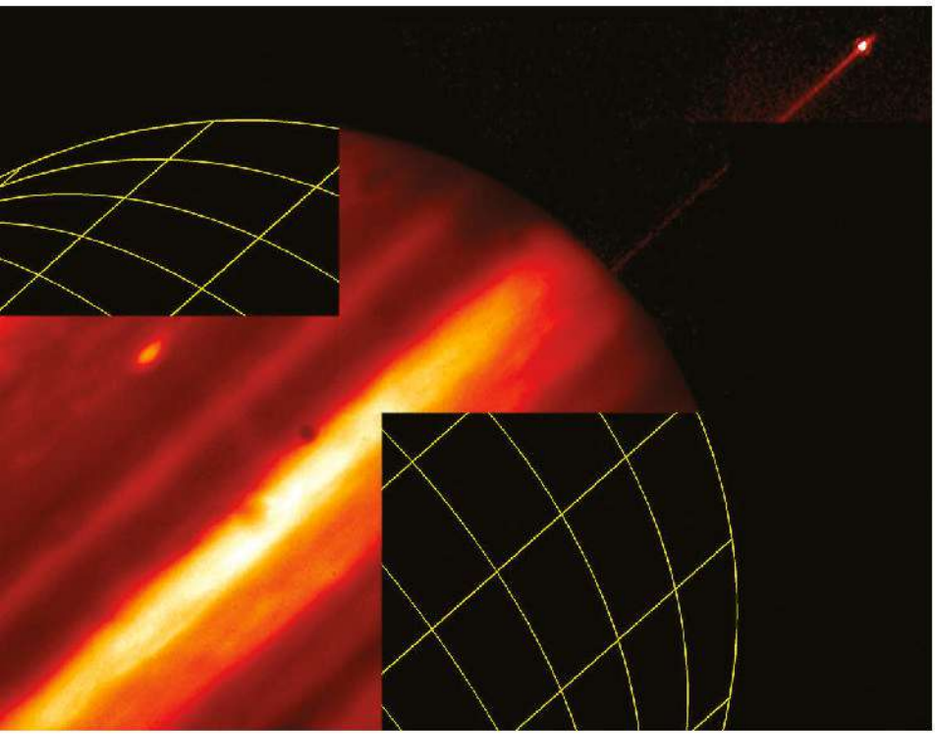
The researchers believe Jupiter has never had large rings in its entire history, or at the very least only had them intermittently. "The Galilean moons have likely been in their present orbital configuration for the age of the Solar System, so Jupiter has never been able to sustain a complex ring system," Kane affirms. The fact Jupiter has rings at all is simply down to the cleaning effect not being as effective in closer radii. "The current tenuous rings of Jupiter are very close to the planet, and they exist largely inside the Roche limit of Jupiter," says Kane. "This means that the present rings are effectively 'hiding' inside the extreme gravitational influence of Jupiter, safe from the perturbing effects of the moons."

But why are the Galilean moons such great ring destroyers while Saturn's moons appear to have far

The James Webb Space Telescope has given astronomers a great look at Jupiter's rings despite them being thinner Saturn's

Taken in 1998, this image shows the main ring of Jupiter using a clear filter

© Stephen Kane/UCR; PNAS; NASA/ESA



THE RINGS OF JUPITER

A look at the rings which circle the Solar System's largest planet

1 The main ring

The main ring is thought to be formed from the dust of two small inner moons, Adrastea and Metis, which orbit in the same location.

2 The halo

The halo ring is a thick torus of particles more than 27,000 kilometres (16,700 miles) above the ring plane. Scientists believe it may be caused by electromagnetic forces pushing small grains out of the ring plane.

3 Gossamer rings

There are two more distant rings: the gossamer rings. There's evidence that they're made up of dust from the moons Thebe and Amalthea and that this dust is constantly being removed and renewed, ensuring the rings never become more than whispers.

"It surprised me that the Galilean moons are so efficient at removing ring material from around Jupiter"

Stephen Kane

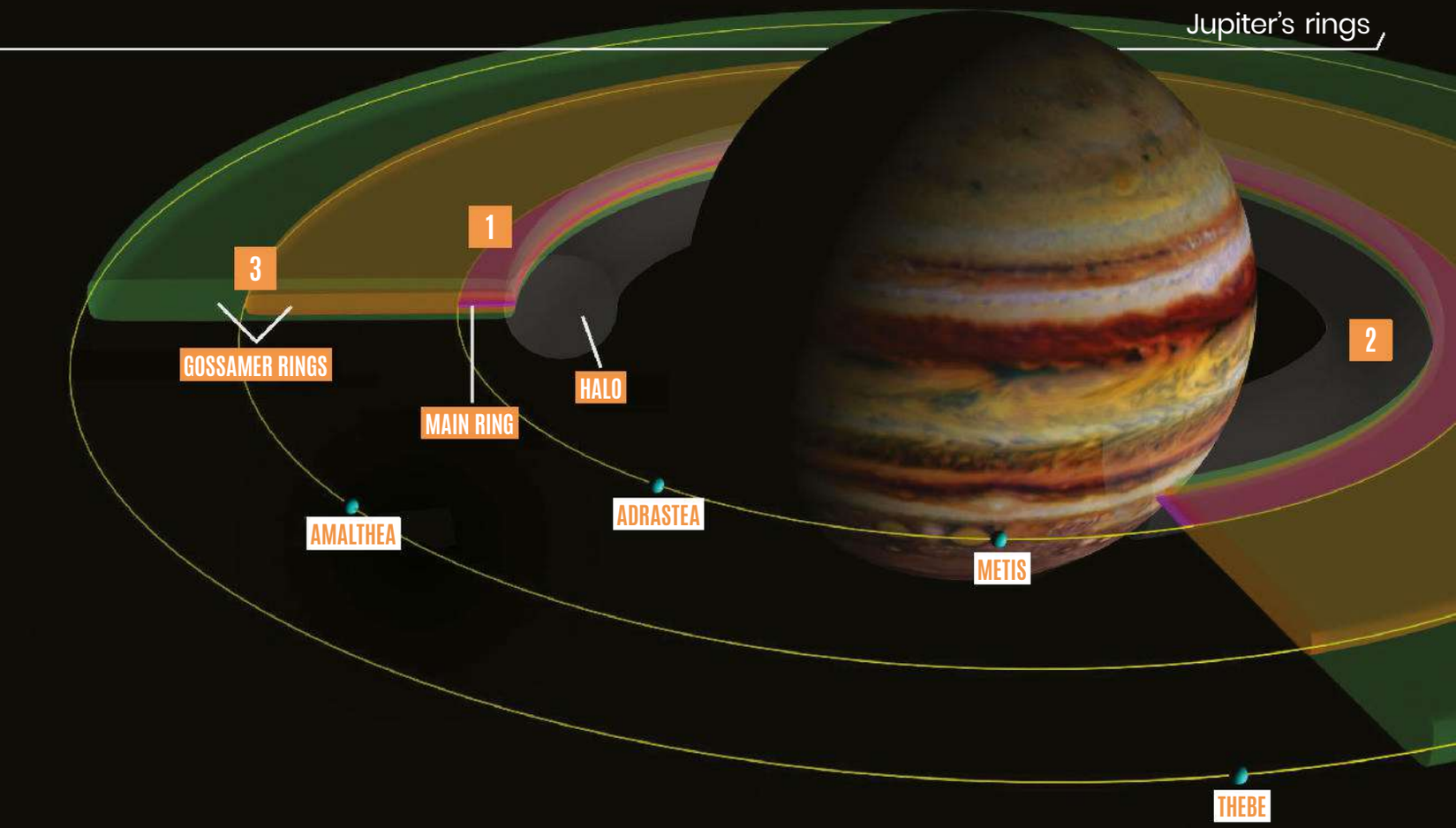
less of an effect? It would appear to be due to a number of factors, most notably the balance between planet mass, the formation of massive moons and the sustainability of significant ring mass. "The efficiency of the ring material removal around Jupiter is largely due to the combination of the inner three moons, Io, Europa and Ganymede. This is because they orbit in a Laplace resonance, which is a simple integer relationship between orbital periods," Kane says. To explain, Ganymede has an orbital period that is four times that of Io, which in turn is twice that of Europa. It's indicative of the moons' migration inwards during Jupiter's formation or soon thereafter, which "may have resulted in a significant gravitational truncation of a potential massive ring system for Jupiter."

As Kane says: "The 4:2:1 Laplace resonance combined with their masses means that the gravity of the moons is able to effectively clear the region around Jupiter where rings would otherwise form on relatively short time scales." Saturn, by contrast, could be close to a so-called 'sweet spot' where, as Kane adds, mass, moons, Hill radius and ring material are balanced. It's a compelling breakthrough, and it would appear to tally with the observations of Jupiter's rings – seen most recently through detailed Near Infrared Camera (NIRcam) long-wavelength filter images taken by the James Webb Space Telescope, which launched in December 2021. Shown to the world in July 2022, the images have since been followed up by sharp images of the rings of Neptune and Uranus.

Hubble provided this infrared view of Jupiter, the inner moon Metis and a faint ring

Uranus also has a prominent ring system

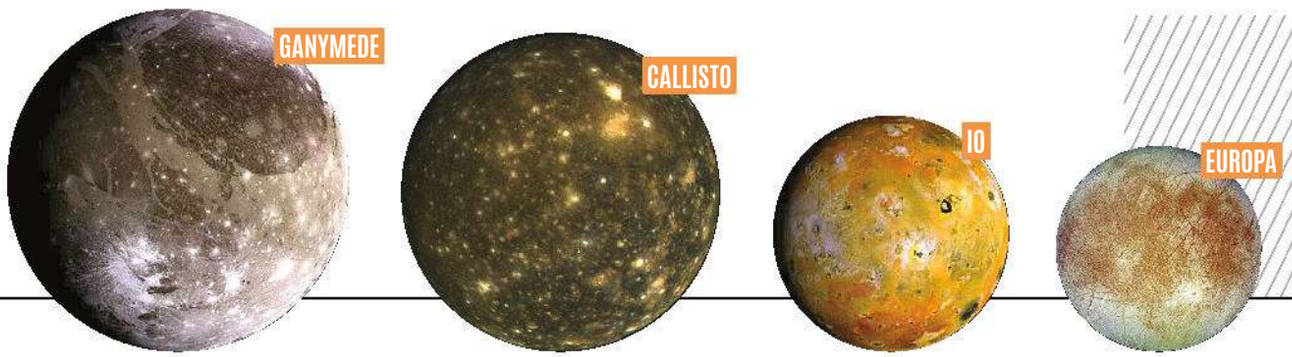
© NASA



Kane and Li are now seeking to use their simulation to study the Uranian rings, which could help clear up another mystery. That's because astronomers have long tried to work out why Uranus orbits the Sun while tipped on its side, and it could well be that it was the result of a huge impact, one that created the rings as well. In fact, the astrophysicists say that the rings hold many historical clues about the gas giants' formation. "Uranus is a fascinating case due to the possible impact scenario, which resulted in both of its rings and extreme tilt," Kane says.

As it stands, the current study has made great strides towards a greater understanding of what has been happening around Jupiter while also giving a better indication of how and why rings form around the other gas giants. The shape, size and position of the rings can tell scientists so much about the events that led to their creation. In that sense, they are a glimpse into the past, a little bit like the rings within a tree trunk. "In general, this study shows that a more massive planet does not necessarily mean more impressive or massive rings, since massive planets are more likely to form a complex moon system that can remove rings," Kane explains. It also makes the presence of rings around a planet even more intriguing. "Rings are both beautiful and complex," Kane continues. "Their formation and evolution is an active ongoing area of research that can teach us about how planets form and the early impact history of the Solar System." Studies are sure to continue for many more years to come.

David Crookes
Science and technology journalist
David has been reporting on space, science and technology for many years, has contributed to many books and is a producer for BBC Radio 5 Live.



These are the prime suspects in the case of Jupiter's less prominent rings

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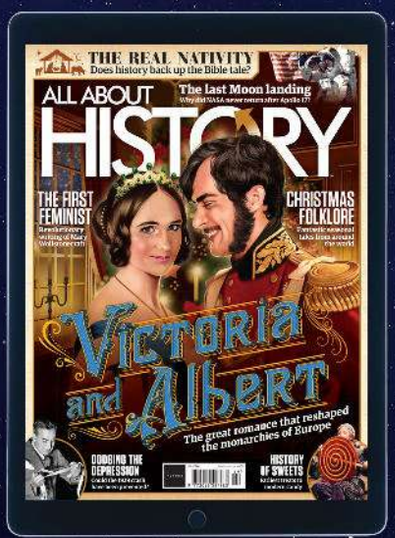

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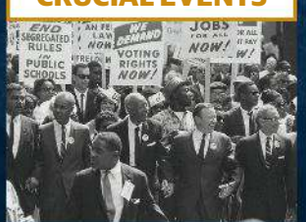	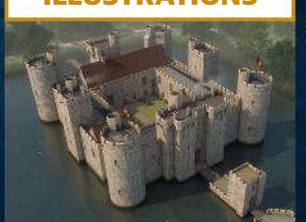	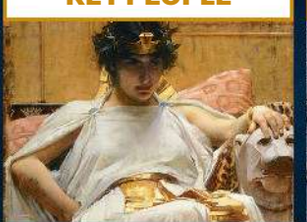		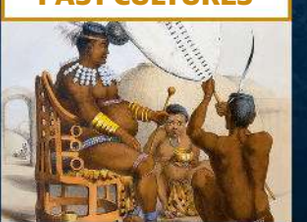

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ASTRONOMY

I want to get started in astronomy. Where do I begin?

One of the first things to do is not to rush out and buy a telescope. People think you need a telescope to enjoy the night sky, and yes, it helps, but there are a lot of telescopes out there and you can end up wasting your hard-earned cash on something that's not right for you. I think the best piece of advice is to go along to your local astronomy society first, because there are a lot of people at societies all over the country who have got a lot of experience, and they can help you make the right choice as to what kind of telescope to get. You might find that, actually, astronomy is not for you, and if you've spent £4,500 ($5,400) on a telescope you might be a bit peeved by it! I think by going to an astronomical society you can see what kind of telescopes are out there, talk to people about what kind of things in astronomy inspire you and then make sure you buy the right telescope for you, rather than waste money on something that you might not actually need.

Mark Thompson, astronomer, television presenter and writer best known for being part of the BBC show *Stargazing Live*

© Getty Images

EXOPLANETS

Is there a chance that Kepler-452b's atmosphere is exactly like Earth's?

To be honest, we don't know what the atmosphere is like on Kepler-452b. It could be that it has an atmosphere similar to that of Earth, but it could also be the case that it retains more hydrogen than helium, and that would mean that it would have a much thicker atmosphere. This means it may be much hotter at the surface, so in this case it may not be habitable. For example, in our own Solar System the closest thing we have to Earth is Venus. Indeed, this planet has an atmosphere that in some ways is similar to our own – it has a lot of carbon dioxide and very little nitrogen, but it is very thick. That's because all of the carbon is in the atmosphere rather than in rocks, so its atmosphere is 90 times thicker in terms of the pressure at the surface than Earth's atmosphere. Venus is hot enough to melt lead, so on Earth we're very fortunate that biological processes keep carbon in rocks in the form of calcium carbonate. That is why Earth has a much thinner atmosphere than Venus.

Jon Jenkins, former team member of the Kepler Space Telescope

"It could be that it has an atmosphere similar to that of Earth, but it could also be the case that it retains more hydrogen than helium"

SPACE EXPLORATION

Can you see the stars when you're spacewalking?

You can see the stars very clearly when you are outside on a spacewalk. The human eye works very similar to a camera in the way the f-stop of a camera is adjusted. In bright sunlight your pupils close down very tightly and you can only see the brightest things in the field of view – for example the Sun, Earth or the Moon. But if you look into the deep darkness of space, your eyes will accommodate the darkness, your pupils will get bigger and you can see the trillions and trillions of stars out there very clearly. Probably the coolest thing I've seen out on a spacewalk is actually flying through an aurora, which are very pale multicoloured lights that extend from the poles up into space. It's just spectacular.

Dr Scott Parazynski, former NASA astronaut and physician

We need much better telescopes to probe distant exoplanets

Astronauts get the very best views of the stars

ASTROPHYSICS

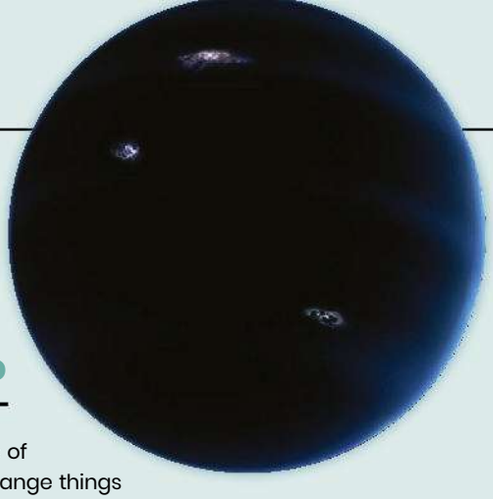
If our universe were a simulation, would we know?

Imagine you're playing any of the *Mario* games, and let's say you are in the game. You start taking measurements and you say, "If I jump, I jump this high, and the other characters don't jump as high as I do." You start setting up laws of motion that apply inside the game; eventually you might figure out all the laws of motion, and that is your world. But is that anything different to what we're doing with our branches of science? We're trying to figure out the laws of nature. Where do those laws come from? It's still a little bit of a mystery. Religious people would say a god made the laws, but if you're more prone to secular accounts of things, you might ask are these coming about naturally or by hand, by someone who has created our world for their own entertainment. And then you get deeply philosophical and say if we are a simulation of some super-intelligent alien species, is that indistinguishable from people's concept of god? That's another interesting path to have a debate over a beer at a bar, something to start arguing about because everyone is going to have an opinion no matter how much or little research they've done on it.

Neil deGrasse Tyson, director of the Hayden Planetarium at the Rose Center for Earth and Space in New York

SPACE EXPLORATION

Why do we think a Planet Nine exists?



Over the past couple of years, two different teams of astronomers pointed out that there were some strange things going on in the outer Solar System – some of the objects that travelled the farthest from the Sun seemed to have a set of properties that was hard to explain. Both teams of astronomers suggested there was another planet in the outer Solar System, but they couldn't figure out how it could get there. A few years ago, I was looking through sets of data and I realised they had missed some of the key properties of the outer Solar System. I walked down the hall to my colleague Konstantin Batygin's office and I said, "Look, there's something going on out there and we need to figure this out." That's when it really started.

Dr Mike Brown, professor of planetary astronomy at the California Institute of Technology

Planet Nine would lie far beyond Pluto

Working out all the laws of nature could give us clues

Astronauts on the International Space Station experience microgravity

"Both teams suggested there was another planet in the outer Solar System"

SPACE EXPLORATION

How does it feel to be in zero gravity?

There's no way to simulate weightlessness properly on Earth. You can be fooled into thinking that it's going to be the same as a simulator here on Earth, but something I learned a long time ago is that all simulators are wrong. You have to remember that as a test pilot and as an astronaut. The simulator is just a way to get close enough to reality that hopefully you'll be able to deal with reality when it occurs. That's what a simulation is; it's not reality. When you actually get to space and you unstrap from your chair and you come floating up into weightlessness, it's permanent. It doesn't stop as soon as the aeroplane pulls out or as soon as your feet touch the ground. We're so used to being pulled down by gravity that it almost feels like you're being pulled up because you're so used to your hair being pushed down on your head and your clothes on your skin. You're used to your tongue being pushed to the bottom of your mouth and you don't even think about it. You are used to having the spit in your mouth at the bottom of your mouth. But suddenly when there's no gravity, everything feels like it's being pulled up towards the ceiling by invisible strings. It feels like instantaneous magic because suddenly you can tumble and float and fly. It's great.

Chris Hadfield, retired Canadian astronaut

© Getty Images

Did you know?

Phobos is the largest Martian moon and orbits the Red Planet in just eight hours.

SPACE EXPLORATION

Will astronauts ever land on the surface of Phobos?

Not Phobos, because it doesn't have much gravity, so it wouldn't be practical to colonise. Popular opinion is that Phobos and Deimos are actually captured asteroids, so we could use them for other things instead of setting up a base. First off, we could do Mars sample return missions from either moon because there is a lot of debris from Mars on those moons. This is because over billions of years Mars shot up debris from the surface thanks to now-dormant or extinct volcanoes and meteorite impacts, so scientists think we could find an awful lot of samples of Mars on the surface of Phobos and Deimos, using robots to search for them. Another reason scientists want to go to the moons is to better understand asteroids. One of the discussions we've had in the US for over a decade now is whether we should stop at an asteroid before going to Mars, and if you go to Phobos or Deimos you're killing two birds with one stone, because if they are asteroids you can learn about both Mars and about small asteroidal bodies by going to them. To land a robot on Phobos, you would need some kind of system of harpoons and drills like the lander on the Rosetta probe had, and a lot of thruster moves because there isn't enough gravity to land like you would on Mars.

Chris Carberry, executive director and co-founder of Explore Mars, a nonprofit organisation created to advance the goal of sending humans to Mars

While the main goal is getting to Mars, its moons could also be a target for human exploration

WHAT'S IN THE SKY?

What to look out for during this observing period

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26 JANUARY
Conjunction between the Moon and Jupiter in Pisces

26 JANUARY
The Moon and Jupiter make a close approach, passing within 1°48' of each other in Pisces

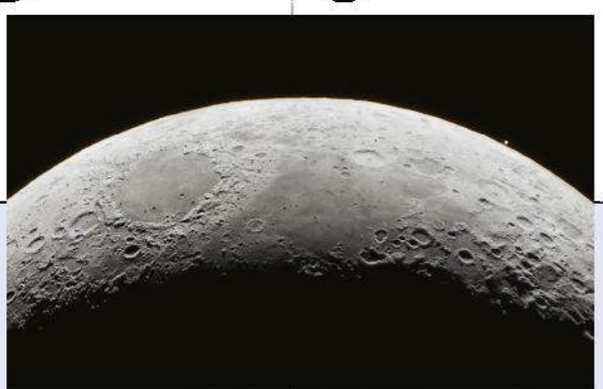
26 JANUARY
Asteroid 6 Hebe is well placed for observation, glowing at magnitude +8.7 in Cancer

29 JANUARY
The Moon and Uranus make a close approach, passing within 52.8' of each other in Aries

29 JANUARY
The Moon will pass in front of Uranus, visible from parts of North America

30 JANUARY
Mercury reaches its greatest elongation west in the dawn sky, dazzling at -0.2

31 JANUARY
Conjunction between the Moon and Mars in Taurus



31 JANUARY
Comet 96P/Machholz will make its closest approach to Earth at +4.0 in Aquarius

31 JANUARY
Comet 96P/Machholz will make its closest approach to the Sun, predicted to reach +4.0

31 JANUARY
The Moon and Mars make a close approach, passing within 6.2' of each other in Taurus

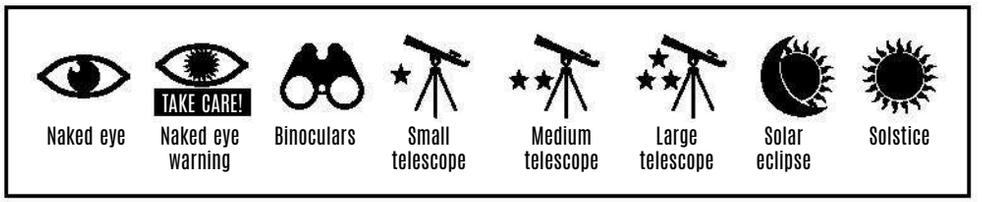
31 JANUARY
The Moon will pass in front of Mars, visible from parts of the Americas

1 FEBRUARY
Comet C/2022 E3 (ZTF) will make its closest approach to Earth at +4.6 in Camelopardalis

19 FEBRUARY
Messier 81 (Bode's Galaxy) is well placed for observation at +6.9 in Ursa Major

22 FEBRUARY
Conjunction between the Moon and Jupiter in Cetus and Pisces

22 FEBRUARY
The Moon will pass in front of Jupiter, visible from parts of South America and Antarctica



22 FEBRUARY

Conjunction between the Moon and Venus in Pisces

22 FEBRUARY

The Moon and Venus make a close approach, passing within 1°50' of each other in Pisces

22 FEBRUARY

The Moon and Jupiter pass within 1°03' of each other in Cetus and Pisces

Red-light friendly

In order to preserve your night vision, you should read our observing guide under red light

"Comet 96P/Machholz will make its closest approach to Earth at +4.0 in Aquarius"

Jargon buster

Conjunction

An alignment of objects at the same celestial longitude. The conjunction of the Moon and the planets is determined with reference to the Sun. A planet is in conjunction with the Sun when it and Earth are aligned on opposite sides of the Sun.

Declination (Dec)

How high an object will rise in the sky. Like Earth's latitude, Dec measures north and south in degrees, arcminutes and arcseconds. There are 60 arcseconds in an arcminute and 60 arcminutes in a degree.

Opposition

When a celestial body is in line with Earth and the Sun. During opposition, an object is visible for the whole night, rising at sunset and setting at sunrise. At this point in its orbit, the celestial object is closest to Earth, making it appear bigger and brighter.

Right Ascension (RA)

RA is to the sky what longitude is to Earth, corresponding to east and west. It's measured in hours, minutes and seconds, as since Earth rotates on its axis, we see different parts of the sky throughout the night.

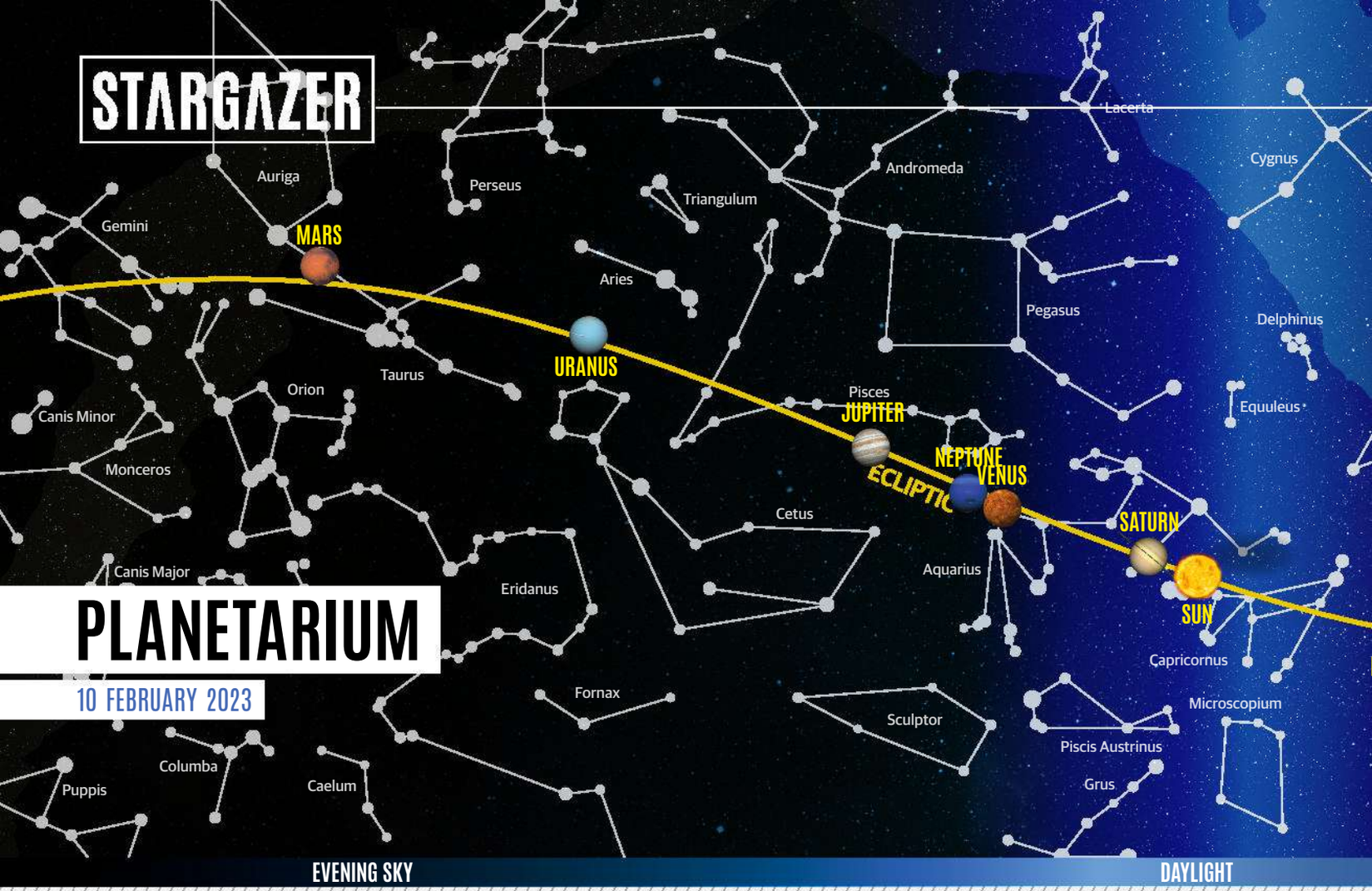
Magnitude

An object's magnitude tells you how bright it appears from Earth, represented on a numbered scale. The lower the number, the brighter the object. A magnitude of –1.0 is brighter than +2.0.

Greatest elongation

When the inner planets, Mercury and Venus, are at their maximum distance from the Sun. During greatest elongation, the inner planets can be observed as evening stars at greatest eastern elongation and as morning stars during western elongation.

© NASA; Getty Images



PLANETARIUM

10 FEBRUARY 2023

MOON CALENDAR

* The Moon does not pass the meridian on 5 February

27 JAN	28 JAN	29 JAN	30 JAN
40.5%	FQ 51.3%	61.6%	71.2%
10:23 --:--	00:21 10:37	01:39 10:53	02:56 11:14

31 JAN	1 FEB	2 FEB	3 FEB	4 FEB	5 FEB	6 FEB
79.7%	87.0%	92.8%	96.9%	99.3%	FM --:--* %	99.8%
04:10 11:41	05:18 12:18	06:17 13:05	07:03 14:04	07:38 15:11	08:03 16:23	08:22 17:35

7 FEB	8 FEB	9 FEB	10 FEB	11 FEB	12 FEB	13 FEB
98.4%	95.1%	90.0%	83.2%	75.0%	65.4%	TQ 54.8%
08:38 18:47	08:50 19:58	09:02 21:10	09:13 22:23	09:25 23:39	09:38 --:--	00:58 09:56

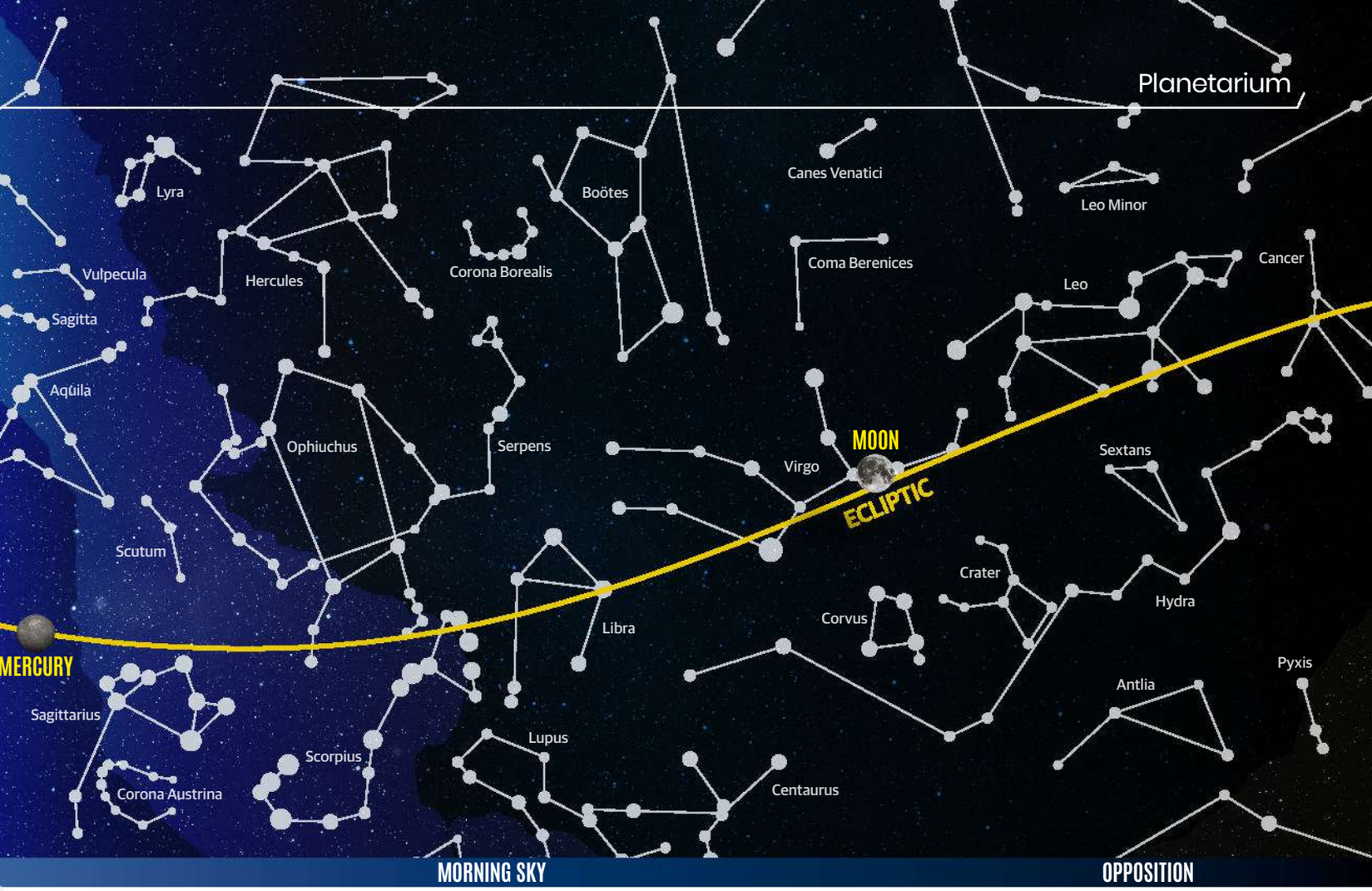
14 FEB	15 FEB	16 FEB	17 FEB	18 FEB	19 FEB	20 FEB
43.6%	32.4%	21.7%	12.4%	5.4%	1.2%	NM 0.2%
02:21 10:20	03:44 10:55	05:01 11:48	06:04 13:00	06:49 14:28	07:20 16:03	07:42 17:37

21 FEB	22 FEB	23 FEB	24 FEB
2.5%	7.6%	14.9%	23.9%
07:59 19:08	08:14 20:34	08:27 21:58	08:41 23:20

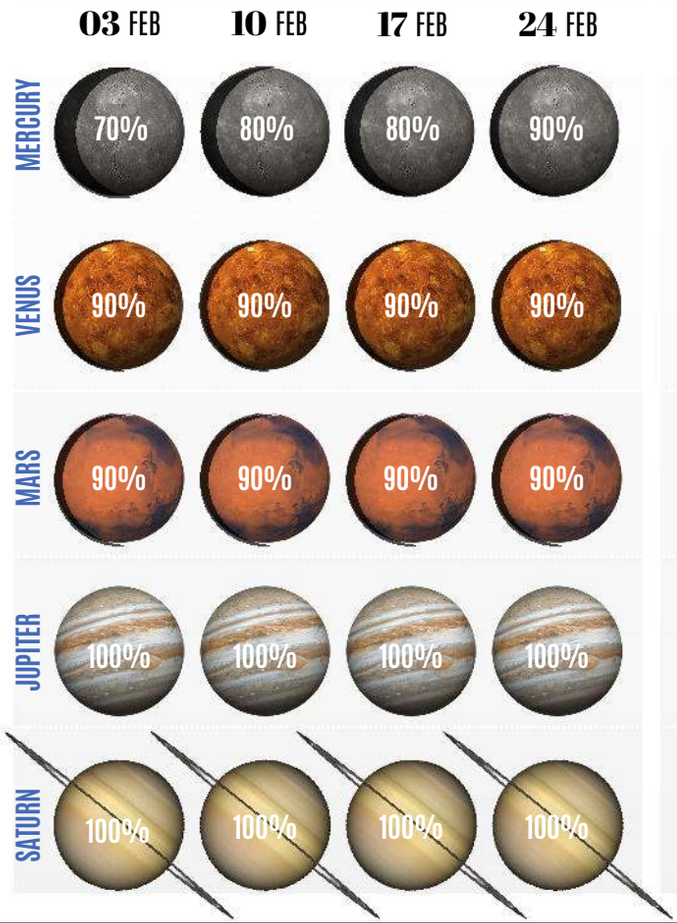
% Illumination
Moonrise time
Moonset time

FM Full Moon
NM New Moon
FQ First quarter
TQ Third quarter

All figures are given for 00h at midnight (local times for London, UK)



ILLUMINATION PERCENTAGE



PLANET POSITIONS

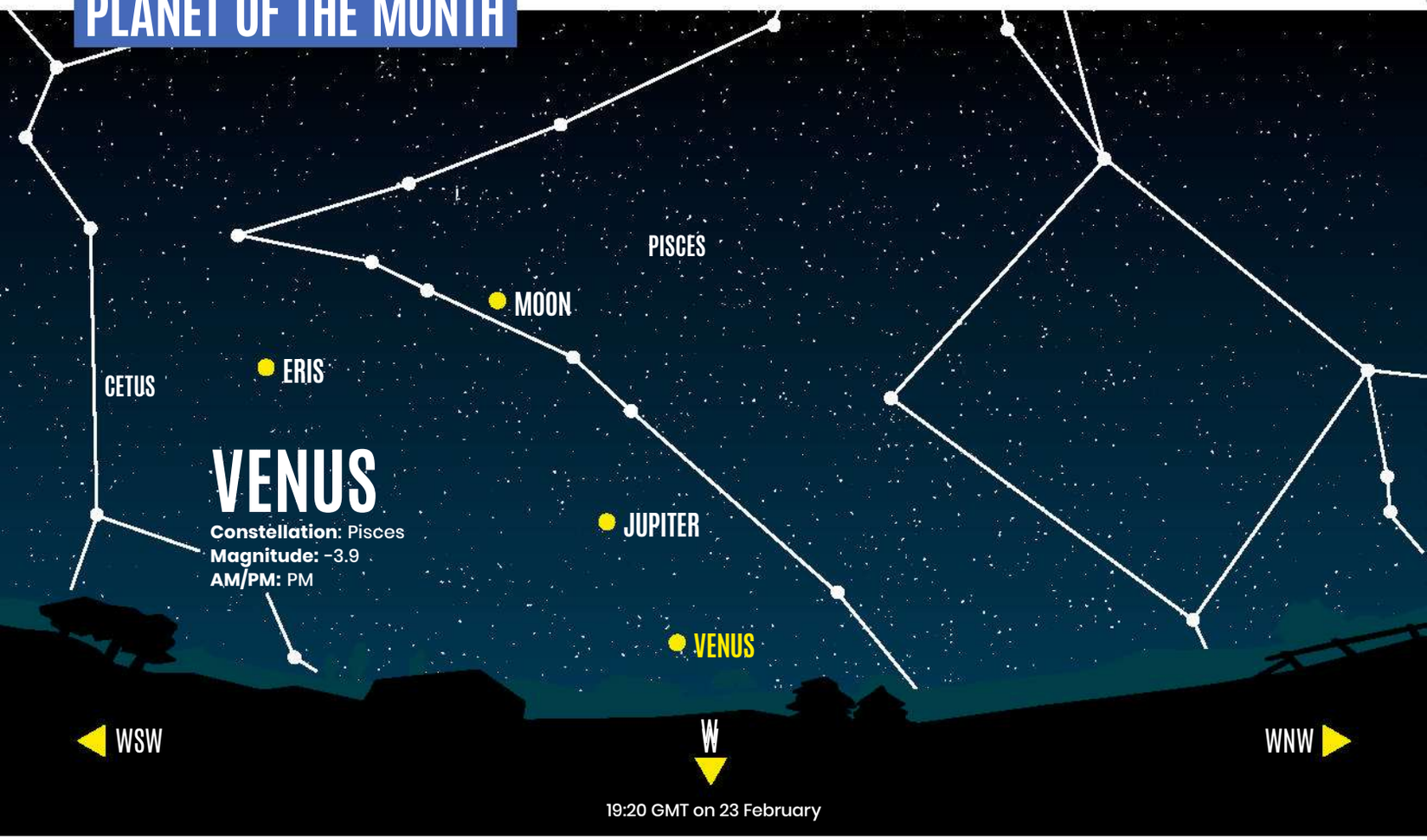
All rise and set times are given in GMT

DATE	RA	DEC	CONSTELLATION	MAG	RISE	SET
27 JAN	18h 50m 41s	-21° 22' 45"	Sagittarius	-0.1	06:21	14:32
3 FEB	19h 21m 31s	-21° 44' 11"	Sagittarius	-0.2	06:26	14:32
10 FEB	19h 59m 33s	-21° 14' 09"	Sagittarius	-0.1	06:33	14:46
17 FEB	20h 41m 20s	-19° 44' 19"	Capricornus	-0.2	06:38	15:10
24 FEB	21h 25m 14s	-17° 11' 22"	Capricornus	-0.4	06:38	15:42
27 JAN	22h 08m 52s	-13° 05' 43"	Aquarius	-3.9	08:49	18:39
3 FEB	22h 41m 49s	-09° 50' 49"	Aquarius	-3.9	08:36	19:02
10 FEB	23h 13m 59s	-06° 23' 27"	Aquarius	-3.9	08:23	19:25
17 FEB	23h 45m 33s	-02° 48' 00"	Pisces	-4.0	08:08	19:47
24 FEB	00h 16m 46s	+00° 51' 17"	Pisces	-4.0	07:53	20:09
27 JAN	04h 27m 23s	+24° 31' 16"	Taurus	-0.4	11:35	04:28
3 FEB	04h 33m 27s	+24° 40' 07"	Taurus	-0.2	11:12	04:07
10 FEB	04h 41m 23s	+24° 51' 05"	Taurus	-0.0	10:51	03:49
17 FEB	04h 50m 55s	+25° 02' 55"	Taurus	+0.2	10:32	03:33
24 FEB	05h 01m 49s	+25° 14' 26"	Taurus	+0.3	10:14	03:18
27 JAN	00h 19m 34s	+00° 49' 08"	Pisces	-2.2	09:46	22:02
3 FEB	00h 24m 18s	+01° 21' 06"	Pisces	-2.2	09:21	21:42
10 FEB	00h 29m 19s	+01° 54' 46"	Cetus	-2.2	08:55	21:22
17 FEB	00h 34m 37s	+02° 29' 52"	Cetus	-2.1	08:30	21:03
24 FEB	00h 40m 08s	+03° 06' 10"	Pisces	-2.1	08:05	20:44
27 JAN	21h 50m 37s	-14° 22' 44"	Capricornus	+0.8	08:38	18:14
3 FEB	21h 53m 50s	-14° 06' 12"	Capricornus	+0.8	08:12	17:51
10 FEB	21h 57m 05s	-13° 49' 21"	Capricornus	+0.8	07:46	17:28
17 FEB	22h 00m 22s	-13° 32' 17"	Aquarius	+0.8	07:20	17:06
24 FEB	22h 03m 38s	-13° 15' 10"	Aquarius	+0.8	06:54	16:43

THIS MONTH'S PLANETS

Venus enters the evening sky, prepared to dazzle astronomers

PLANET OF THE MONTH



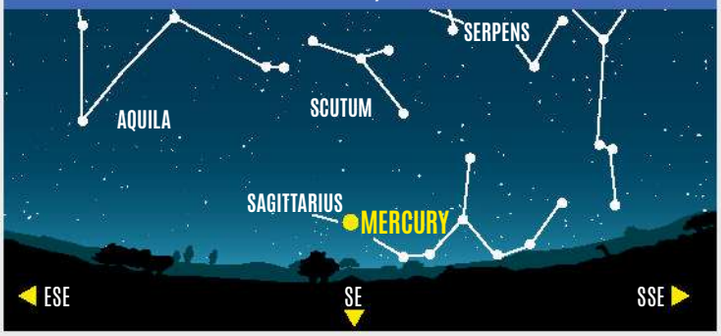
At the end of January Venus will be a bright 'evening star' shining low in the southwest after sunset. You'll see it glinting there as soon as darkness falls, looking like a bright silvery-white spark in the sky. You won't be able to miss it. At the end of January Venus will have company in the sky – the ringed planet Saturn will be close by, shining just down to its lower right, much fainter to see than Venus itself but still visible to the naked eye. As January drifts into February Venus and Saturn will pull apart a little further each evening, and Venus will appear to close in on Jupiter, to its upper left. But if you have binoculars you'll be able to see Venus having a close encounter of the cosmic kind with another planet, a planet that can't even be seen with the naked eye.

On the evening of 14 February the most distant planet from the Sun, Neptune, will lie less than a degree away from Venus. Through binoculars or a telescope you'll see it as a tiny, blue-green star to Venus' lower right, less than two Moon widths away. By the following evening the two worlds will have swapped places, and Neptune will be to Venus' upper left, but even closer than the night before, and the two will be a very pleasing sight in binoculars and telescopes.

By now Venus will be setting more than two-and-a-half hours after the Sun, and will be a lovely sight in the western twilight sky, easily the brightest thing in that direction. But you really need to cross your fingers for clear skies between 21 and 23 February, because Venus will have a lot of company in the sky. After dark on the 21st, a very thin fingernail clipping of a crescent Moon will shine almost directly below it. The following evening, the 22nd, the Moon will be shining to the upper left of Venus, between it and Jupiter. By now the dark part of the Moon's face should be lit with the faint lavender glow of Earthshine, so the view will be quite beautiful, and you should try photographing it with the camera on your phone, or a DSLR if you have one.

By 23 February the Moon will have moved on and will be to the upper left of Jupiter, but it will still be a very striking view. To see this parade of worlds at its best you'll need a flat skyline to the southwest so trees, hills or tall buildings don't obscure the celestial lineup. By 25 February Venus and Jupiter will be less than four degrees apart in the sky, and will look like a lovely 'double star'.

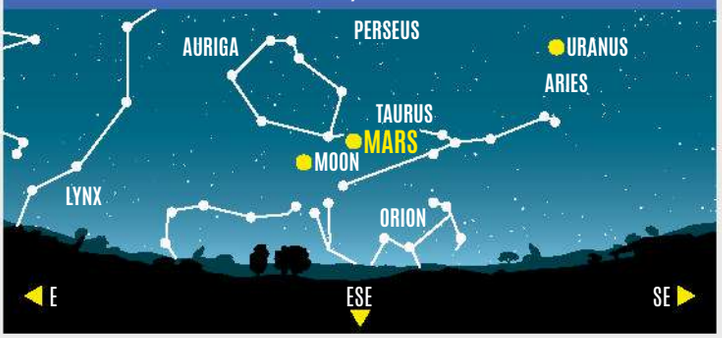
MERCURY 07:00 GMT on 30 January



Constellation: Sagittarius **Magnitude:** -0.0 **AM/PM:** AM

As January draws to a close, Mercury, the nearest planet to the Sun, will be a 'morning star' shining low in the southeast before sunrise, looking like a copper-hued star. Rising only an hour before the Sun, it will still be low as the sky begins to brighten with the approach of dawn. You might need binoculars to pick it out.

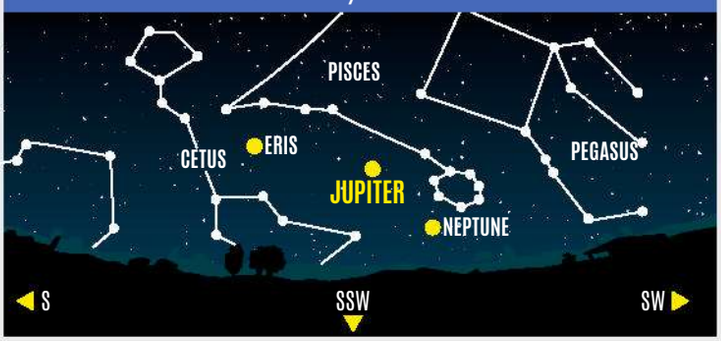
MARS 16:00 GMT on 28 February



Constellation: Taurus **Magnitude:** +0.4 **AM/PM:** PM

Through January and February Mars will already be visible high in the southeast as twilight deepens. Mars will be visible all through the night, not setting until a few hours before sunrise. Look out for a bright waxing gibbous Moon to the right of Mars on the evening of 30 January, and to its left the following evening.

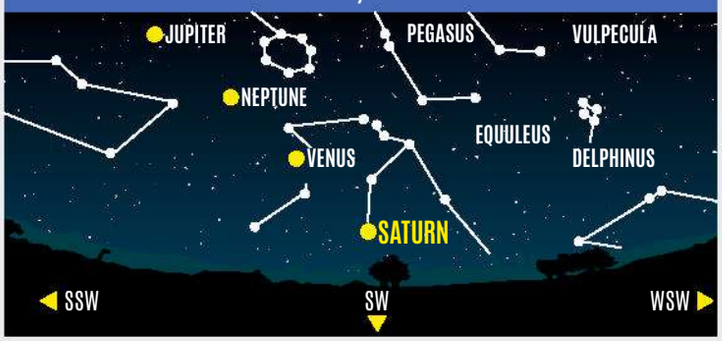
JUPITER 17:00 GMT on 8 February



Constellation: Pisces **Magnitude:** -2.2 **AM/PM:** PM

At the end of January Jupiter will be a bright blue-white star high in the south after sunset, shining to the upper left of the close pairing of Venus and Saturn, which will be low in the southwest. At the start of February Jupiter will set some five hours after the Sun, but its visibility decreases steadily during our observing period.

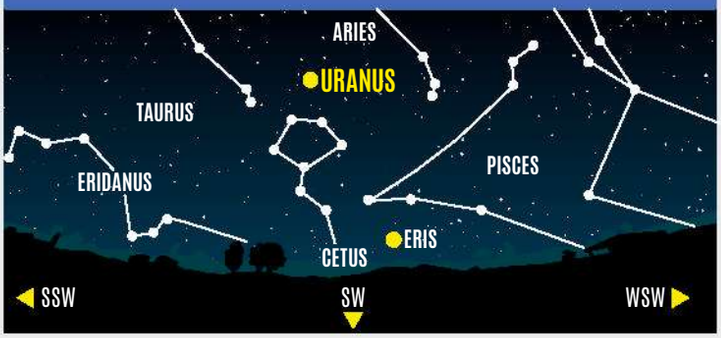
SATURN 16:00 GMT on 5 February



Constellation: Capricornus **Magnitude:** +0.8 **AM/PM:** PM

Saturn will be very low in the sky after sunset, so you'll only have a short time to see it. At the end of January Saturn will be very low in the southwest, a short distance to the lower right of much brighter Venus. As February progresses Saturn will gradually become lost in the Sun's glare, vanishing by 14 February.

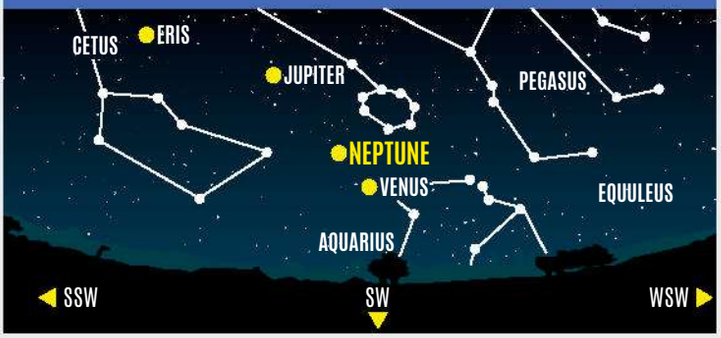
URANUS 19:00 GMT on 12 February



Constellation: Aries **Magnitude:** +5.7 **AM/PM:** PM

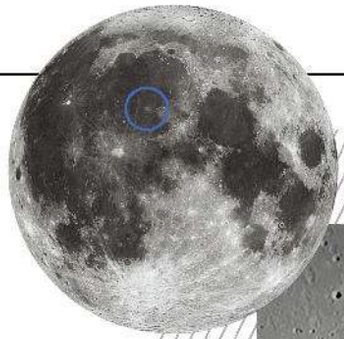
As January ends Uranus will lie between ruddy Mars and blue-white Jupiter, and by the end of February will be roughly halfway between them, as Mars will have pulled away. A bright first quarter Moon will blaze close to Uranus on the evening of 28 January, to its lower right, and the following evening will have moved to its upper left.

NEPTUNE 17:00 GMT on 10 February



Constellation: Aquarius **Magnitude:** +8.0 **AM/PM:** PM

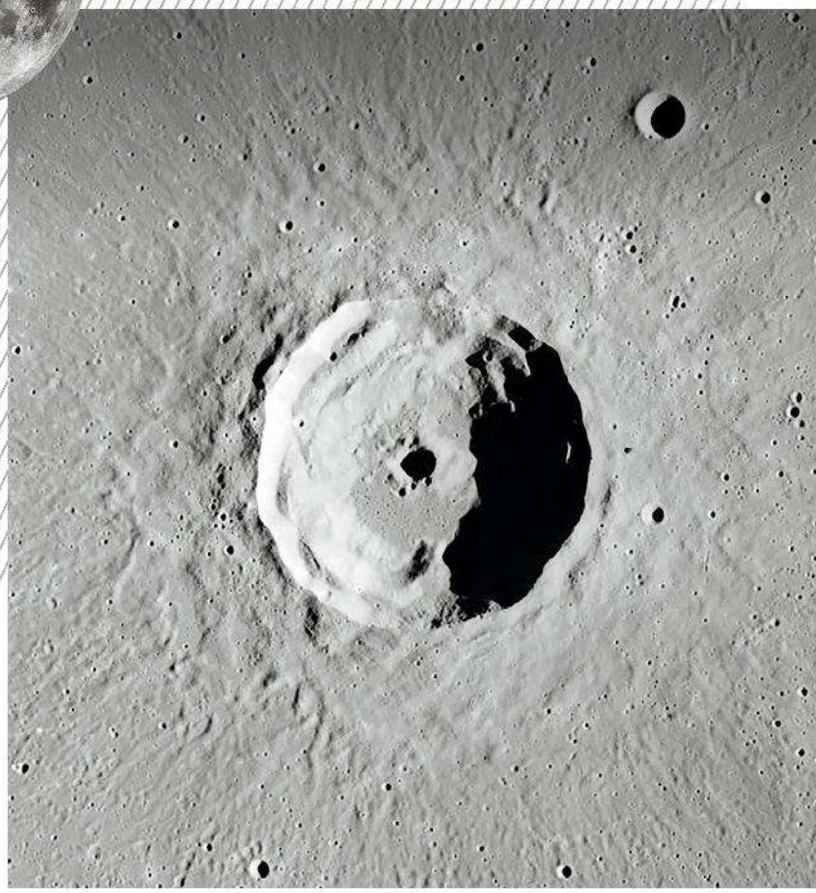
At the end of January Neptune will be very close to much brighter Jupiter in the evening sky, setting around 21:00. As the days pass Neptune will be approached by brilliant Venus from its lower right. On the evening of 14 February they will be less than a degree apart, and the following evening even closer.



MOON TOUR

TIMOCHARIS

Go on a sightseeing tour of a little crater with a very violent past



Up near the top of the lunar disc, nestled in the curve of the rugged Montes Apenninus, is a small crater called Timocharis. It doesn't look like anything special; the Moon is spattered with countless tens of thousands of craters just like it, each one proof that our satellite has been absolutely pummelled and pulverised in its distant past by asteroids and comets that were left circling the Sun after it was born 4.6 billion years ago. Some of these impact craters are enormous, and lunar observers gaze at them again and again, ignoring the smaller holes surrounding them. But some of these small craters have fascinating stories behind them too, and deserve more than just a fleeting glance, such as Timocharis.

The crater was named in 1651 by the skilled lunar cartographer and observer Giovanni Battista Riccioli to honour the Greek astronomer and philosopher Timocharis, who not only worked in the famous Great Library of Alexandria, but very accurately measured lunar star occultations and observed a planetary occultation by Venus.

Timocharis lies in the Sea of Showers, or Mare Imbrium, a vast, dark plain of ancient frozen lava which represents one of the eyes of the 'Man in the Moon'. It is just 34 kilometres (21 miles) across and three kilometres (1.86 miles) deep. It forms a tight triangle with its much bigger near neighbours, enormous 96-kilometre (59.6-mile) Copernicus to the southwest and 59-kilometre (36.6-mile) Eratosthenes directly to its south.

In lunar terms Timocharis is a relatively young feature, as is proven by the fact that it's not surrounded by any major bright beams or pale splashes of debris. At full Moon you can see some subtle rays spreading away from Timocharis, but they are pale imitations of those which surround its bigger, older neighbours. If you take the time to hunt it down with your telescope, a high-power eyepiece will reveal Timocharis to be a surprisingly complicated feature. It's roughly polygonal in shape, with sharp, rugged outer walls, the inner slopes of which are broken up into multiple ledges and terraces. In some places these have slumped down towards the crater's floor. When sunlight is striking Timocharis from a steep angle – for example when it's near the terminator, it can look like a stony bullseye in the eyepiece.

On still evenings of really good seeing, a high-power eyepiece will show Timocharis has a central mountain peak – or rather it used to. Once, long ago, a towering mountain rose above Timocharis' floor, but now there is a small, deep crater there. Some time after Timocharis was formed, an asteroid came barrelling in from deep space and slammed into the mountain at its centre, obliterating it and scattering its shattered pieces across the crater floor, leaving behind a hole which now stares out from the heart of Timocharis like an empty eye socket. Many of the countless tiny craters you'll see spattered across Timocharis' floor and slopes were probably formed by that same impact.

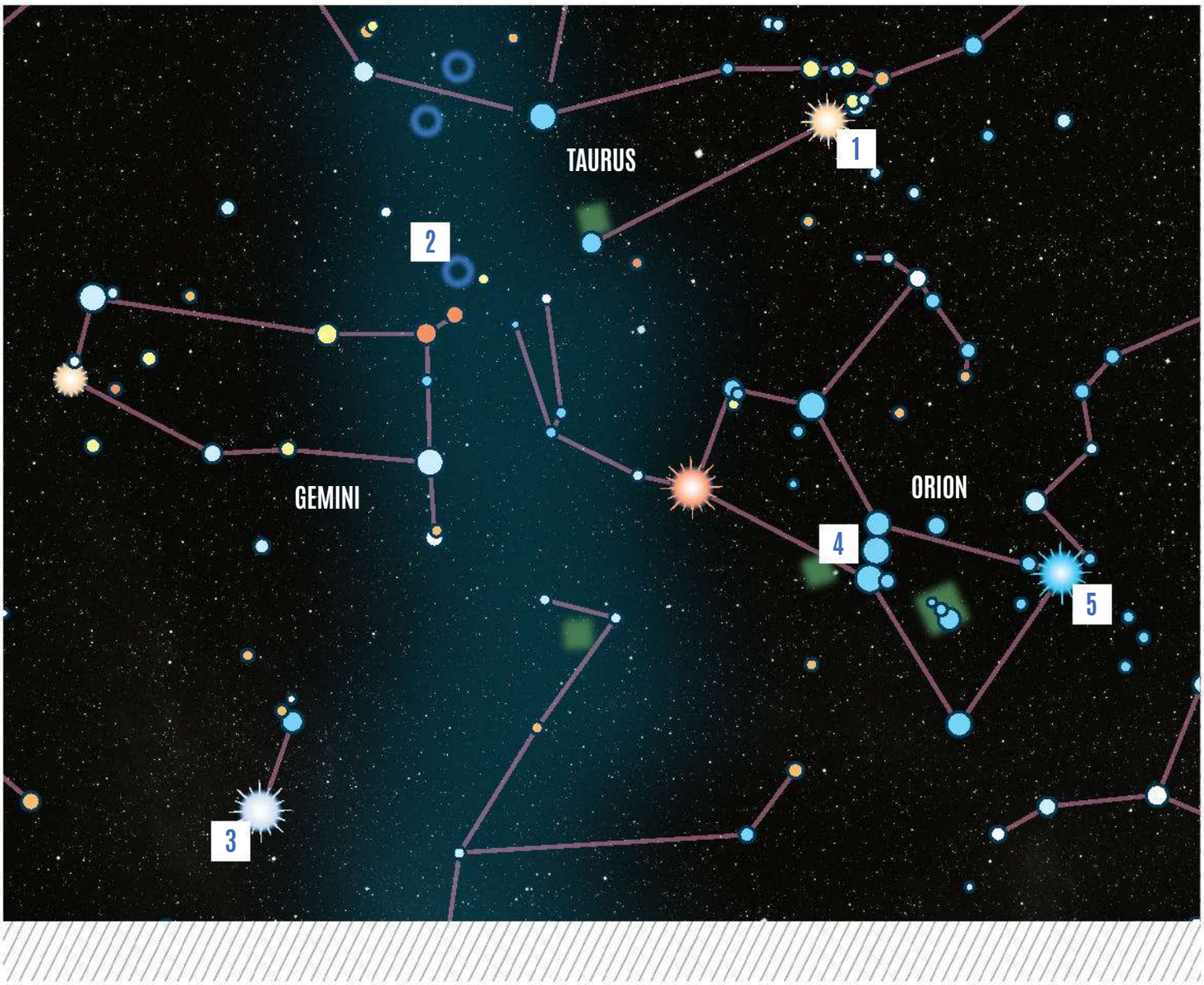
On 30 January, the Moon will be in its waning gibbous phase, just a few days away from full, so Timocharis will be in full sunlight. At this time, seen through a telescope the crater will be a pale-grey ring with a dark centre. It won't be until 9 February, when the Moon is approaching its last quarter phase, that the crater will begin to show any kind of detail. With the setting Sun's rays coming in at a lower angle, the crater's walls and internal features will cast shadows that will make them stand out more clearly.

By 12 February the crater will stand out starkly in an eyepiece, looking like a round pit with a jumbled floor, and subtle details on its surrounding slopes will be more obvious too. On 14 February the terminator will be almost upon the crater, and this is when it will look most dramatic through a telescope – even a small one will show it standing out very clearly. By the next evening Timocharis will have been enveloped in darkness, and it will remain in darkness until the evening of 1 March, when the Sun rises above its local horizon and sunlight splashes over its walls and down onto its jumbled floor once more.

TOP TIP!

Timocharis will be most obvious when it is close to the terminator, when the Sun's rays illuminate it from a low angle.

© NASA



NAKED EYE AND BINOCULAR TARGETS

February's night sky is rich in pretty star clusters and bright colourful stars

1 Hyades (Caldwell 41)
The Hyades is a distinctive V-shaped star cluster representing the shoulder of Taurus, the Bull. It's only 142 light years away, contains between 300 and 400 stars and is easy to see with the naked eye. However, dazzling bright-red Aldebaran is not a cluster member, as it lies between us and the cluster.

2 Messier 35
Messier 35 is an open star cluster 3,000 light years away and more than 24 light years wide. It contains perhaps 3,200 stars, and although it can be seen as a tiny smudge to the naked eye, it is a striking sight in binoculars and most small telescopes.

3 Procyon (Alpha Canis Minoris)
Magnitude +0.3
Procyon is the eighth-brightest star in the sky. Its name means 'before the dog' in Greek, and it does indeed rise into the sky before Sirius, the much brighter 'Dog Star'. It is 14 light years away, making it the 14th-closest star to our Sun.

4 Orion's Belt
One of the most famous patterns of stars in the entire sky, Orion's Belt is made up of three blue-white stars of approximately the same brightness. Astronomers use it as a pointer to guide them to other sky sights. It gestures down to Sirius, the brightest star in the sky, and up to the Hyades star cluster.

5 Rigel (Beta Orionis)
Shining at magnitude +0.18 in Orion's bottom-right corner, Rigel is the brightest star in Orion and the seventh-brightest in the sky. About 860 light years from Earth, it's a blue-white 'supergiant' star 17 times more massive than our Sun and an amazing 40,000 times more luminous.

3 The Jellyfish Nebula (IC 443)

DEEP SKY CHALLENGE

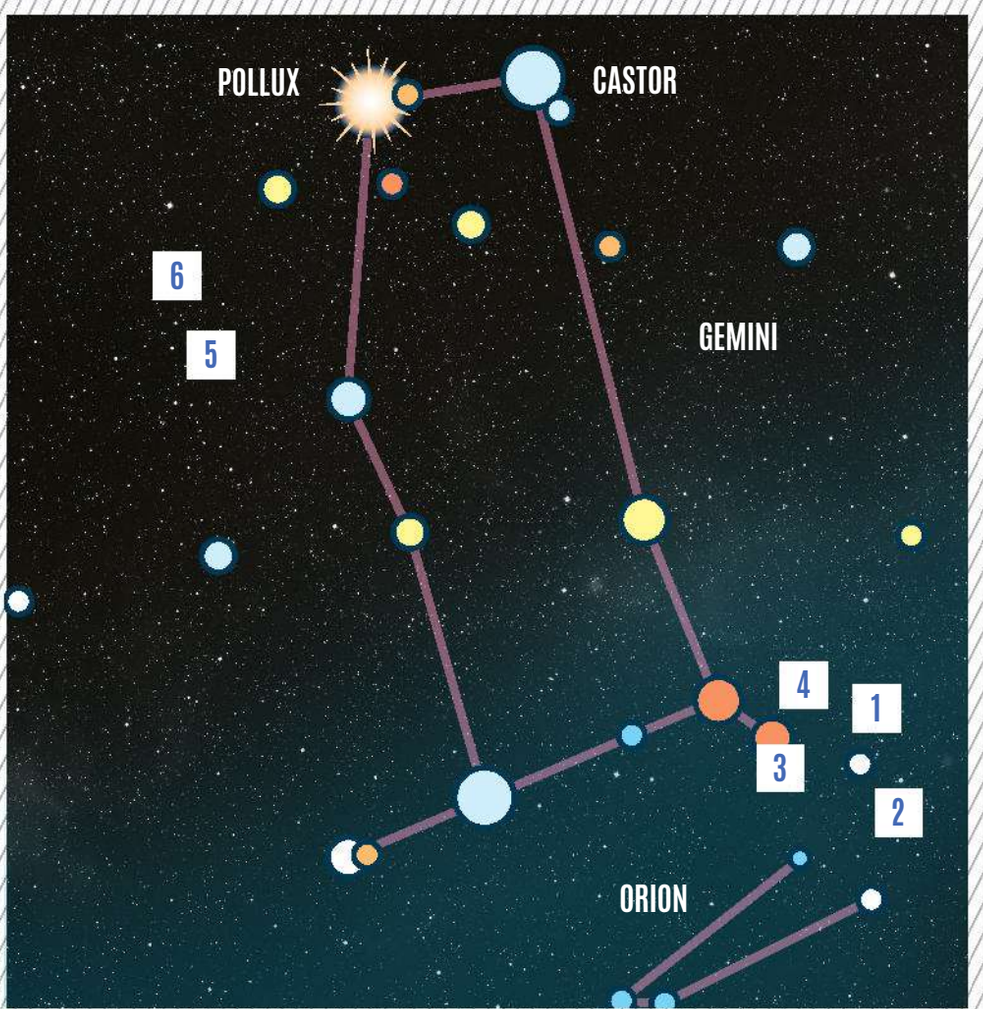
THE EXOTIC NIGHT SKY OBJECTS OF GEMINI

Dig deep in the constellation of 'the Twins' and you'll find some of winter's best-kept secrets

Gemini, also known as the Twins, sits nicely about halfway up the sky at this time of year and contains many lovely objects for those armed with a telescope. These vary from open star clusters to faint nebula and even a supernova remnant. The two bright stars that mark out the constellation are interesting too. Alpha Geminorum, known as Castor, is a lovely star system composed of three binary pairs all linked together by gravity, and Beta Geminorum, known as Pollux, is an orange giant star and is known to have an extrasolar planet orbiting about it. Though it's a simple constellation, there's plenty to see.

6 NGC 2420

5 The Eskimo Nebula (NGC 2392)



1 Messier 35

You only need a small telescope with low magnification or suitable binoculars to enjoy Messier 35, which is scattered over a large, elongated area. Averted vision can reveal some of the stars under dark skies.

2 NGC 2129

Use a medium-power telescope to thoroughly observe this small but attractive star cluster. It's very young; its age has been estimated at around 10 million years, so you'll be feasting your eyes on blue-white stars.

3 Jellyfish Nebula (IC 443)

Showing up in long-exposure images, this beautiful nebula is the remains of a supernova, an exploded star that shed its outer layers. An OIII filter will assist in observing, and should reveal a bright arc of gas and dust.

4 IC 444

This reflection nebula is quite close to IC 443 and yet is distinctly separate. Despite not taking up a large proportion of sky, it's much easier to image due to its higher surface brightness, shining at a magnitude of around +7.0.

5 Eskimo Nebula (NGC 2392)

Looking like a person's head in a hood, this lovely object is a planetary nebula – a star that has ejected its outer layers. With a magnitude of roughly +10.0, locating the Eskimo Nebula is easy with a telescope of at least a medium aperture and favourable night sky conditions.

6 NGC 2420

Within the grasp of a small to medium telescope, this cluster can appear as a smudge in averted vision. Around 25 stars can be viewed with amateur equipment, although at least 650 members are suspected to exist there.

© NASA; NOAO

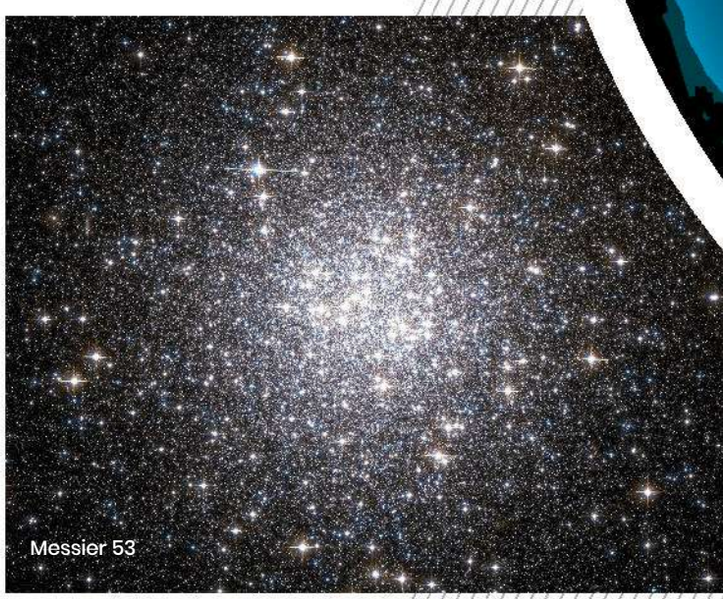
THE NORTHERN HEMISPHERE

Orion fades to the southwest while Leo climbs from the east

Leo (the Lion) takes pride of place in the night sky, cutting a regal figure as its leading star – hot, blue Regulus – shines at magnitude +1.36, an unmissable sight. Galaxies are also in abundance here, from the spiral arms of Messier 95 to the featureless-yet-prominent form of Messier 105, as well as a selection of binary stars, including Rho Leonis. Leo is bordered by Cancer, Coma Berenices, Crater, Hydra, Leo Minor, Lynx, Sextans, Ursa Major and Virgo, the latter of which also offers a selection of galaxies to be enjoyed. If your interests lie in tracking down nebulae and star clusters, head over to the Great Bear for the Owl Nebula or seek out the Beehive Cluster, also known as Praesepe or Messier 44, in the Crab.

Beehive Cluster (Messier 44)

Winter Milky Way


Messier 53

Using the sky chart

This chart is for use at 22:00 mid-month and is set for 52 degrees latitude.

1. Hold the chart above your head with the bottom of the page in front of you.
2. Face south and notice that north on the chart is behind you.
3. The constellations on the chart should now match what you see in the sky.

Magnitudes

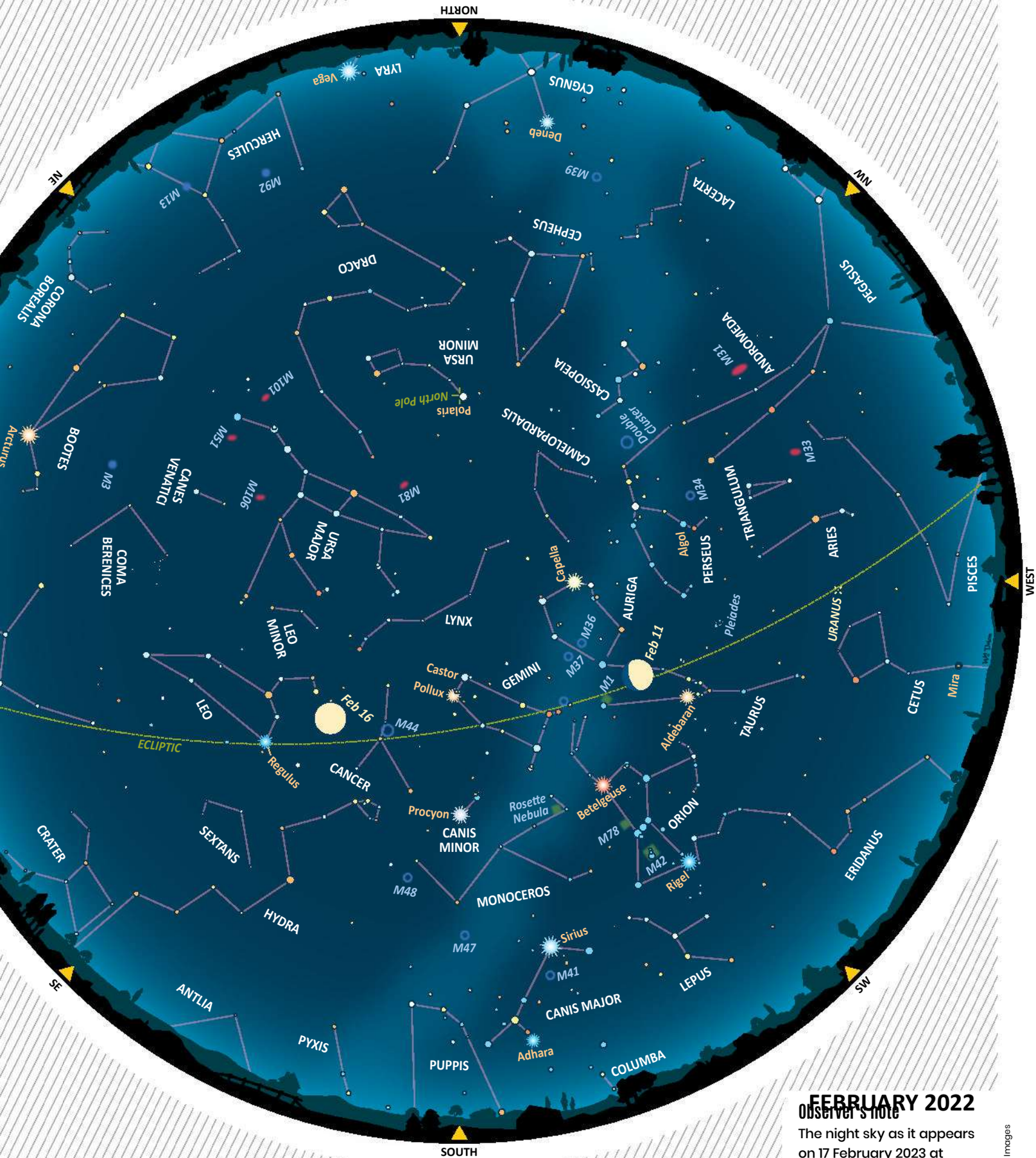
- Sirius (-1.4)
- -0.5 to 0.0
- 0.0 to +0.5
- +0.5 to +1.0
- +1.0 to +1.5
- +1.5 to +2.0
- +2.0 to +2.5
- +2.5 to +3.0
- +3.0 to +3.5
- +3.5 to +4.0
- +4.0 to +4.5
- Fainter
- Variable star

Spectral types

- O–B
- A
- F
- G
- K
- M

Deep-sky objects

- Open star clusters
- Globular star clusters
- Bright diffuse nebulae
- Planetary nebulae
- Galaxies



FEBRUARY 2022

Observer's note

The night sky as it appears on 17 February 2023 at approximately 22:00 (GMT)

© Getty Images

ASTROSHOTS OF THE MONTH

ANDREI PLESKATSEVICH

Location: Minsk, Belarus

Telescope: Askar FMA180

"Over the course of several months I imaged some of my favourite targets: the North America Nebula, Pelican Nebula, Flaming Skull Nebula and Spaghetti Nebula, the Andromeda Galaxy, the Pleiades, Triangulum Galaxy and the Veil Nebula. I have been imaging for several years, improving on my technique to create some results I'm very pleased with."

A portion of the Veil Nebula

Carina Nebula (NGC 3372)

SOUMYADEEP MUKHERJEE

Location: West Bengal, India, and El Sauce Observatory, Chile

Telescope: Takahashi FSQ-106ED and Telescope Live

"I'm an amateur photographer from India and have been imaging objects in the sky for the last 1.5 years. My first image shows a location near the bright star Rigel. IC 2118 is an extremely faint reflection nebula spanning almost 70 light years across. It is popularly known as the Witch Head Nebula. My second image frames the heart of the Carina Nebula, a gem of the Southern Hemisphere sky."

Witch Head Nebula (IC 2118)

PREMJITH NARAYANAN

Location: Kingdom of Bahrain

"Knowing there would be a partial eclipse of the Moon rising from the horizon, I thought I could relate the eclipse to some terrestrial objects. At the horizon the Moon will usually be a blazing orange, and I also wanted to get the reddish tinge of Earth's shadow. Our planet's shadow covered 60 per cent of the Moon's surface, so I decided to select the highest point around the location to get a clear view of the seaside, along with any passing boats."

Blood Moon

REVIEW

ASTRONAUT STARRY SKY STAR PROJECTOR

Perfect for any space fan, this charming device offers great value for money with a great deal of fun thrown in

Reviewed by Tantse Walter

Star projectors are a quick and easy way to change a room's entire feel, and the Astronaut Starry Sky Star Projector is no different. How could we resist this on-brand astronaut wearing a spacewalking suit? We wanted to see if it performed as well as its more discrete counterparts or if it's just a novelty item that lacks the functionality we've come to expect from a quality star projector. One thing we did notice when shopping around for this product is that prices between retailers seem to vary wildly. Unless we were to purchase one from every store

PROJECTOR ADVICE

From: Amazon

Cost: £31.99 / $34.99

Size: 120 by 113 by 228 millimetres

Bulb type: Class 1 laser and LEDs

Rotation: Yes

Sleep timer: 45 and 90 minutes

"This star projector has been cleverly integrated into the body of a spacesuit-wearing astronaut"

and touch and use them, we can't really see any noticeable differences between the advertised models, but we'd advise buying from a reputable seller to ensure you aren't getting a poor-quality replica.

This star projector has been cleverly integrated into the body of a spacesuit-wearing astronaut. The stand resembles the Moon's surface with footprints, which is where the astronaut's feet slot in to keep the astronaut upright and stable.

Everyone who walked in on us reviewing this star projector called it cute. It's now known as 'the little guy', and it's adults we're talking about here. It does have an endearing presence. The USB-A to DC power cable plugs into the astronaut's backpack – in real life, this would be the Primary Life Support System – and this is also where the power button and two mode buttons sit. The lights and lasers shine from the astronaut's space helmet. The astronaut's head attaches to the body with a pretty strong magnet. We like that it can be connected in almost any position. The head can't be lifted off with one hand, and it stays attached when you turn it upside down, making it feel strong and sturdy. You can also pose the little arms vertically into the position you want.

Before reviewing this projector, we'd expected it to feel cheap and toyish to the touch, with a poor-quality finish. While it is a novelty item, we were pleasantly surprised with the build quality, which is actually pretty good. Aside from the slightly plasticky feel to the buttons, it feels solid in the hand and has some weight, thus not like a cheap toy. It wouldn't be out of place in an adult or teenager's bedroom as well as a younger child's room.

The star projector features what appears to be an almost-identical lighting module to the BlissLights Sky Lite 2.0 and the Encalife Atmosphere Smart Galaxy Star Projector. Having reviewed many star projectors, it's clear that a large percentage of them use this same, or a very similar module, but vary how the module is packaged. In this case, it's presented as an astronaut and is operated via remote control. The output, in terms of power and area coverage, is slightly less than some of the other models we've tested, but this is perhaps as it's likely going to be in a room where the projection area isn't going to be huge.

We first reviewed the Astronaut Starry Sky Star Projector in the daytime with natural light coming in through the windows. As with the models mentioned earlier, the stars and nebula aren't at all scientific like they are in the Sega Toys Homestar Flux or the National Geographic Astro Planetarium, but are very bright and otherworldly and can be customised into various configurations and speeds. The lights and laser dots are clearly visible, and the colours are rich and easily distinguishable. The darker the environment, the more impressive the display.

Comparable with the BlissLights Sky Lite 2.0, the motor which rotates the lights is exceptionally quiet; you can only really hear it if you press your ear right up against it. This makes it perfect to use as a night light to drift off to sleep. One difference between this model and the BlissLights Sky Lite 2.0 is there is no option to rotate the lasers that shine from the top right of the astronaut's helmet – only the nebula rotates. We don't think that's a deal-breaker, though.

Despite the novelty appeal of this astronaut, the design cleverly enhances functionality. The astronaut's head is attached by a magnet. While it doesn't easily come apart – which is a good thing – it can very easily be rotated to adjust the projection direction. You should be able to get the light projection at the angle you want regardless of where you place it.

The stand's simple design keeps the astronaut in place, and even when pushed to test for wobble, the

BEST FOR...

- WELLNESS
- FAMILIES
- THE HOME

A remote means you can control the stars from a distance

The astronaut would be perfect for a child's bedroom

device doesn't fall over. It would take some force for it to fall off a shelf or table.

The supplied remote control, which needs two AAA batteries that aren't included, can be used to operate the astronaut's features. You can adjust the brightness, turn the lasers on and off and adjust the 'breathing' frequency of the lasers and nebula. You can switch the colours of the nebula, change the speed of the nebula's rotation and adjust the brightness of the lights. You can use the buttons on the device itself to operate some of the functions, but you'll need the remote to adjust the rotation speeds and to use the sleep timer, so don't lose it! Our little astronaut features a sleep timer that can be set to either 45 or 90 minutes. There's a little indicator on the astronaut's backpack. When it's blue, the 45-minute timer is on; when it's red, the 90-minute timer is active. This works seamlessly.

The Astronaut Starry Sky Star Projector is a cost-effective way to add immediate ambiance to a room. Thanks to its novelty spacewalking astronaut design, it would be the perfect gift for a young space fan. It's very easy to use, the lights are bright and customisable, the lasers will fill a small room and the operation is quiet, all features that make for a good star projector. It even looks great when it's left idle, unlike the more practical projectors.

As we mentioned, the difference in price between retailers can be huge. Make sure you buy from a reputable company where returns are accepted, just in case you end up with a cheap copy of this good-quality item. For scientific accuracy, you'll want to look at Sega Toys Homestar Flux or the National Geographic Astro Planetarium, though these will cost you more. The latter of the two features an in-built speaker, and the star projections are true to the time and date you select, though it lacks the sophisticated appeal of the Homestar Flux. Of course, you don't get the cute astronaut figurine, but these might be more appropriate for an adult. The lights and lasers are marginally more impressive.

For a basic laser pointer to fill your child's room with coloured 'stars' or to add some atmosphere to a games room or music room, BlissLights have the tiny BlissLights StarPort USB projector, which would fit the bill, although we'd recommend it only for children of an age who know not to look directly into the laser beam.

FOR

- ⊕ Good build quality
- ⊕ Impressive and effective lighting
- ⊕ People of all ages will like it

AGAINST

- ⊖ DC port feels dated
- ⊖ Light output not as good as other models
- ⊖ No speaker

▲ Even when not projecting the stars, the little astronaut makes a nice space-themed decoration

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IN THE SHOPS: BEST SMARTPHONES FOR ASTROPHOTOGRAPHY

Apple iPhone 13 Pro Max

Cost: £1,549 / $1,599
From: Apple

1 Unsurprisingly, Apple is a big hitter in this guide, and its 6.7-inch flagship smartphone is top of the range. The bigger sensor on this camera phone means it produces brighter photos even in low light and at night. It also has a high-quality Night Mode, meaning decent images of the night sky are possible, and if you're ever in the Arctic Circle, that means good photos of the aurora borealis are also possible. That Night Mode automatically kicks in when it's dark, just like the built-in high dynamic range (HDR) mode for all your shots. Simplicity is complemented by advanced hardware, with the latter boasting a 3x optical and 15x digital zoom.

Samsung Galaxy S21 Ultra

Cost: £820.39 / $999.99
From: Samsung

2 A large part of why this is one of the leading Android camera phones is its incredible 108-megapixel image sensor. Although technically you can take ultra-high resolution images, that massive megapixel capability is there to improve pictures taken in low light. The 6.8-inch Galaxy S21 Ultra takes nine separate 12-megapixel images and then loses the 'noisy' pixels to create a cleaner and more detailed photo. You can also use that sensor to take pure 108-megapixel images, but why would you need to do that? Especially since you can't expand its maximum built-in storage of 512GB. The 10x optical and whopping 100x digital zooms are more interesting for photographers, which can be helpful when you put the Galaxy S21 Ultra on a tripod.

Huawei P40 Pro+

Cost: £459 / $718
From: Huawei

3 The P40 Pro+ brings 10x optical zoom via an actual zoom lens – a first when the phone launched in 2020 – which means more detail and editing options than any resolution-killing digital zoom. However, there's a lot more to get excited about on this 6.58-inch smartphone, which brings no fewer than seven lenses, including a 3x optical telephoto ultrawide lens and a time-of-flight depth sensor. Its Night Mode boosts dynamic range and sharpness to produce clean, colourful images that most obviously reveal more detail in shadows. It also works well on the telephoto lens, though less well on the ultrawide lens. Unfortunately, Huawei smartphones now don't support Google Play apps and services, which may make them less desirable.

"Some of the changes do make this handset better for photography"

Google Pixel 6 Pro

Cost: £849 / $899
From: Google

4 This is the best around for in-camera software and photo editing. Fire up the camera app and you'll find all the usual modes, such as portrait, panorama and a low-light mode called Night Sight, but there's also a new mode called Motion that's purely for taking creative long-exposure shots. The 6.7-inch Pixel 6 Pro also comes with advanced new features, including Real Tone and Magic Eraser for removing people and objects from photos after the fact. A 50MP wide lens, a 12MP ultrawide lens and a 48MP telephoto lens with a 4x optical zoom mean the hardware is pretty good. The Pixel 6 Pro is a standout choice, especially as you can choose some unusual colour choices and mix style with substance, and this smartphone definitely has substance.

Apple iPhone 13 Pro

Cost: £1,049 / $1,099
From: Apple

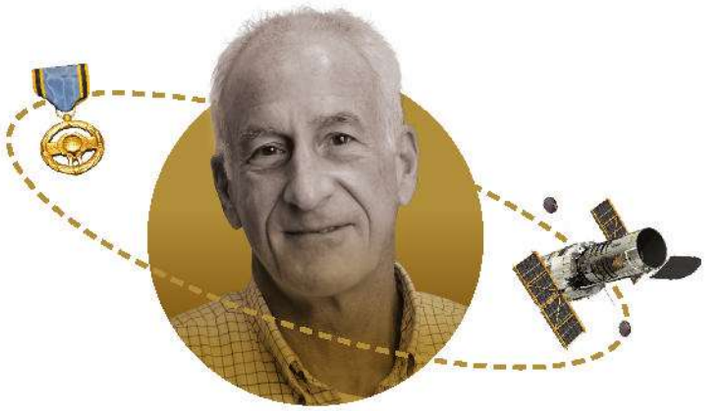
5 Not much has changed design-wise since the iPhone 12 Pro, but some of the changes do make this handset better for photography. There are also some crucial differences between the iPhone 13 and the iPhone 13 Pro. Although both measure 6.1 inches, the latter has a brighter screen, extra battery power and a much better photography suite than the mainstream handset. Its rear camera array includes an ultrawide and a wide lens with larger apertures, a telephoto lens with 3x optical zoom and a LiDAR scanner for quicker autofocus and taking portraits in Night Mode. On the iPhone 13 Pro, it's also possible to take images in professional quality using Apple ProRAW and indulge in ProRes video recording up to 4K at 30 frames per second.

OnePlus 9 Pro

Cost: £529 / $499
From: OnePlus

6 A 6.7-inch handset running Android 13, it sports a stunning AMOLED QHD+ display that beats most smartphones with its colour and black levels. Its camera array on the rear is busy, with four lenses and laser autofocus. So why is there a Hasselblad logo back there? The ultra-high-end medium-format camera photography company has co-developed the 9 Pro's camera array with OnePlus, with Natural Colour Calibration as its substance. Skin tones do look great through its cameras, though the photography highlight is its ultra-wide-angle lens that corrects for edge distortion. Meanwhile, its main camera records in 12-bit RAW, and it has the ability to record in 4K at 120 frames per second and even in 8K at 30 frames per second.

HEROES OF SPACE



JEFFREY A. HOFFMAN

The first astronaut to log more than 1,000 hours on board the Space Shuttle and the man who helped save Hubble

Born in Brooklyn in 1944, he joined NASA in August 1979 following a glittering academic career. He designed, built, tested and flew a balloon-borne gamma-ray telescope for his PhD in astrophysics at Harvard University, and he worked on X-ray astronomy rocket payloads at Leicester University.

When he was selected for STS-61 – the first Space Shuttle flight to repair Hubble – he'd already been on three space missions. His first was STS-51-D in 1985, when he sought to rescue a malfunctioning satellite, and his second was a Spacelab mission in 1990. His third was the first test flight of the Tethered Satellite System in 1992. In the process, he became the first Jewish astronaut and twice gained NASA Exceptional Service Medals. With numerous other special honours, for both his academic and space agency work, he built a strong reputation.

For the work on Hubble, the crew was called upon to add corrective optics, in the guise of extra mirrors, to the telescope. Called the Corrective Optics Space Telescope Axial Replacement (COSTAR), it would aim to put right the slightly misshapen primary mirror that was distorting Hubble's view. Hoffman and Story Musgrave made the longest of the spacewalks during the mission, spending seven hours and 21 minutes outside of the spacecraft. But the hard work paid off. Despite widespread doubts, the mission was a huge success, and Hubble began to send back crystal-clear images. "Our mission was the most ambitious repair mission ever planned by NASA," he reflected in early 2015, when Hubble was celebrating 25 years in space.

While Hoffman also worked on extravehicular activities (EVA), with his duties including the development and testing of a high-pressure spacesuit, as well as new designs and procedures in the assembly of the International Space Station, he made his final spaceflight in 1996. It was during this mission on STS-75 on the Space Shuttle Columbia that Hoffman logged 1,000 hours aboard the Space Shuttle. He would log more than 1,211 hours in space overall, having journeyed 34.6 million kilometres (21.5 million miles).

Hoffman left the astronaut program in 1997 and became NASA's European representative in Paris. He obtained the role of professor of the practice in the Department of Aeronautics and Astronautics at the Massachusetts Institute of Technology in 2002, and six years later a visiting professor at the Department of Physics and Astronomy at the University of Leicester. Highly respected and revered among his peers, Hoffman was inducted into the Astronaut Hall of Fame in 2007.

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Future PLC Quay House, The Ambury, Bath, BA1 1UA

Editorial
Content Director **Gemma Lavender**
gemma.lavender@futurenet.com
Art Editor **Jonathan Wells**
Production Editor **Nikole Robinson**
Senior Art Editor **Duncan Crook**

Contributors
Stuart Atkinson, Mike Brown, Chris Carberry, Charles Q. Choi, David Crookes, Briony Duguid, Chris Hadfield, Robin Hague, Jon Jenkins, Andrew Jones, Sharmila Kuthunur, Robert Lea, John Loeffler, Laura Mears, Scott Parazynski, Giles Sparrow, Mark Thompson, Neil deGrasse Tyson, Stefanie Waldek, Ryan Wells

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Advertising
Media packs are available on request
UK Commercial Director **Clare Dove**
clare.dove@futurenet.com
Advertising Manager **Matthew Johnson**
matthew.johnston@futurenet.com
07974 408 083
Account Manager **Hayley Brailey-Woolfson**
hayley.baileywoolfson@futurenet.com
01643 678 054

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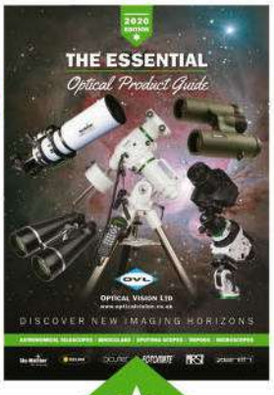

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